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PACE Working Paper:
Solarization of Electric Tube-wells for Agriculture in Balochistan: Economic and Environmental Viability

Prepared as part of the Technical Assistance to the Ministry of Planning, Development and Reform and the Ministry of Power, Government of Pakistan

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(Exchange Rate Effective: September 20, 2019)
Currency Unit = Pakistani Rupee (PKR)
PKR 166 = US$1.00

FISCAL YEAR
July 1 – June 30

Abbreviations, Acronyms, and Special Terms

Abiana	Charges for irrigation water
AEDB	Alternate Energy Development Board
BCR	Benefit-Cost Benefit Ratio
BGWRA	Balochistan Ground Water Rights Administration Ordinance
BID	Balochistan Irrigation Department
CBA	Cost-benefit Analysis
CER	Carbon Emission Rate
CO_2	Carbon dioxide
DISCOs	Distribution Companies for electricity
DoAg	Department of Agriculture
DoE	Department of Energy
FY	Financial Year
GDP	Gross Domestic Product
GoBalochistan	Government of Balochistan
GPS	Global Position System
Ha	Hectare
HEIS	High Efficiency Irrigation System
HP	Horsepower
IBIS	Indus Basin Irrigation System
IFPRI	International Food Policy Research Institute
IMF	International Monetary Fund
IUCN	International Union for Conservation of Nature
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt Hour
M&E	Monitoring and Evaluation
MAF	Million Acre Feet
NPV	Net Present Value

OFWM	On-Farm Water Management
PACE	Pakistan Agriculture Capacity Enhancement
PARC	Pakistan Agriculture Research Council
PCRWR	Pakistan Council of Research in Water Resources
PIDE	Pakistan Institute of Development Economics
PKR	Pakistani Rupee
PMU	Project Management Unit
PSDP	Public Sector Development Programs
QESCO	Quetta Electric Supply Company
R&D	Research and Development
SETs	Solarization of Electric Tubewells
STs	Solar Tubewells
T&D	Transmission and Distribution
US$	United States Dollar
WB	World Bank
ZAC	Zamindar Action Committee

Executive Summary

Balochistan's agriculture and related economic development during the last four decades has been driven by an enhancement in canal command areas and widespread use of tubewells. While it enabled yield increases and the growth of high value horticulture, it led to excessive mining of ground water. It is not only threatening sustainable agriculture and livelihoods but also creating severe environmental repercussions. It is generally believed that this unchecked groundwater extraction has been a result of policy regime, such as promoting installation of tubewells through various incentive schemes and tubewells subsidy which allows farmers to pay only 5-10% of the actual cost, and as a result the Federal and provincial governments have been paying PKR 23 billion per year.

In this backdrop, the Government of Balochistan (GoBalochistan), in collaboration with the federal government, has been considering solarization of 28,088 electric tubewells used for agriculture purpose in the province to reduce electricity subsidy burden. To better understand the economic and environmental impact of the "Solarization of Electric Tubewells (SETs)" project in Balochistan and to support the policy makers in making an informed decision, the International Food Policy and Research Institute-Pakistan under its PACE[1] project has undertaken the study on the request of Energy Section of the Planning Commission and the Department of Agriculture (DoAg), GoBalochistan.

This study assesses the economic and environmental viability and sustainability of converting existing electric tubewells to solar in Balochistan given groundwater depletion and a water crisis following prolonged drought. The study reflects findings from the existing literature, secondary data, and informed opinions gathered through consultative meetings with relevant stakeholders in addition to primary data collected during field visits to various districts of Balochistan.

Data from various sources shows that the water table is depleting at an alarming rate of 30-40 feet per year and at certain places, irreversible "fossil" water is being mined. Overall, 10 out of 19 sub-basins are over-exhausted. In the absence of effective regulatory regime as well as recharge mechanisms and prolonged drought, the groundwater overdraft led to negative consequences on the social and economic wellbeing of the people of Balochistan. Among the most important ones, there has been a loss of agricultural livelihoods, drying of traditional *karezes* and springs, deterioration of water quality and land subsidence (gradual sinking of ground).

For this study, IFPRI conducted several consultative meetings and focus group discussions with relevant stakeholders to evaluate the relative importance, influence, needs, and expectations of these stakeholders. Analysis of their responses reflect varied position of different stakeholders. Large farmers including Zamindar Action Committee (ZAC) along with major secondary stakeholders, including Pakistan Agriculture Research Council (PARC), Pakistan Council of Research in Water Resources (PCRWR), and Alternate Energy

[1] Pakistan Agriculture Capacity Enhancement, funded by USAID

Development Board (AEDB) are very supportive of STs over electric ones and many of them have installed STs. Majority of the primary stakeholders, however, oppose the implementation of the project. Department of Irrigation (DoI) and the Directorate of Extension consider the STs unviable for technical and environmental reasons. QESCO has serious concerns about success of the project. It believes that in the presence of 21,000 illegal connections, farmers are likely to continue with both solar and electric tubewells. Directorate of On-Farm Water Management (OFWM) is mutely opposed to the idea, and Department of Energy (DoE) acknowledged that the STs project is one way to get rid of the subsidy burden. However, they are neutral toward the proposed project.

Cost-benefit analysis (CBA) shows that the project is not economically feasible if cost rises when implementation delays, non-availability of resources, and other factors are included. Recognizing the limitations of cost-benefit analysis that it helps in evaluating economic viability of a project, it is equally important to consider social, environmental and political ground realities as well as other risk factors for a holistic view in this case, albeit behavioral changes that a project could possibly bring. At times, some of the risk factors are difficult to quantify, but they play significant role in determining sustainability of a project. Once done, the project is either very close to break-even point or expected to deliver marginal benefit. When these marginal benefits are weighed against the socio-economic costs and consequential increased inequity, the project does not seem to be viable.

The project may be considered with utmost caution as there are several risk associated which include: (i) over-exploitation and degradation of ground water because of low operational cost making it cheaper to pump water for long hours; (ii) increase in cropping intensity: with marginal cost of pumping ground water nearing zero, farmers could expand area under cultivation as well as increase cropping intensity or simply over-irrigate; (iii) possibility of maintaining dual system of electric as well as STs; and (iv) increasing social displacement and inequity. Several remedial measures are in practice to mitigate these risks though, there is strong evidence that such mitigation measures may not be sustainable in the local cultural context. It is important to undertake institutional and structural reforms to strengthen regulatory regime to mitigate the risks.

It is for these reasons that the study recommends various policy options as well as a comprehensive set of policy actions to address the groundwater depletion, subsidy burden and to harness the agricultural potential of Balochistan if the STs is a political compulsion. These includes: (i) diversification towards low-delta, drought resistant high value crops; (ii) ensuring water use literacy and adoption of modern on-farm water management techniques; (iii) ensuring farmers' access to quality agricultural inputs and their timely availability; (iv) encouraging farmers for water efficient higher yield tunnel farming; (v) reforming agricultural produce markets and incentivizing for value addition and food processing; (vi) strengthening legal regime for water governance and management; (vii) establishing monitoring mechanism for groundwater usage; (viii) institutional reforms and strengthening their capacity and training; (ix) investment in water storages to harness full potential of available water resource that go waste; (x) invest in recharge mechanisms and water conservation practices; (xi) reforming QESCO; and (xii) developing a communication and strategy fully aligned to local culture and traditions. The study also addresses the issue of water pricing for irrigation for creating awareness to adopt water efficient technology and practices, crop diversification, and water conservation.

1 Background

The Government of Balochistan (GoBalochistan), in collaboration with the federal government, has been considering a large-scale conversion of 28,088 electric tubewells[2] to solar energy in the province. The objectives of the proposed project are:

i. Removal of electricity subsidy for tubewells to relieve the federal and provincial governments of the current financial burden.

ii. Adoption of a more sustainable approach to harness the agricultural potential of the province with least environmental impact.

The Department of Agriculture and Cooperation (DoAg &C), GoBalochistan vide its letter No. SOA(Dev)5-7/2014-15 Misc./1022 dated April 2, 2019 approached the International Food Policy Research Institute (IFPRI) Pakistan for undertaking a study to assess impact of solar tubewells (STs), the viability of the proposed project, as well as its effects on water conservation practices in the province. Subsequently, the Energy Wing of the Planning Commission also showed an interest in a holistic assessment of the socioeconomic and environmental impact of the solarization of electric tubewells (SETs) project, along with a rigorous cost-benefit analysis, to facilitate the Government in taking an informed decision regarding the proposed project.

IFPRI-Pakistan recognizes that the challenges are immense, but with perseverance and better strategy, the provincial government can surmount these challenges. The layout of the report is as follows: Section 2 discusses the provincial context and current situation as well as elaborates history of groundwater development in Balochistan. Section 3 provides the scope of the study; Section 4 illustrates the research methodology adopted; Section 5 describes the key challenges; Section 6 highlights the politics of tubewells in Balochistan and Section 7 looks at subsidy on tubewells for agriculture and its impact on water tables in Balochistan. Section 8 examines the institutional and regulatory environment for groundwater management. Section 9 assesses the relative importance, influence, and views of the different stakeholders involved in the project. Section 9 assesses the cost benefit analysis and Section 10 includes a detailed sensitivity analysis of the installation of solar tube wells. Finally, Section 11 and 12 concludes the study by highlighting key policy recommendations and the way forward respectively.

2 Provincial Context: Situation Analysis

Balochistan is the largest province, constituting 44% of Pakistan's total land mass with population of, according to the 2017 census, 12.344 million. Balochistan is rich in exhaustible and renewable resources and is the second major supplier of natural gas in the country. Local inhabitants have chosen to live in towns and have relied on sustainable water resources for thousands of years.

[2] 28,088 tubewells are currently operational out of 30,887 installed in Balochistan.

Agriculture development, as the mainstay for the people in Balochistan during the last four decades, has been largely driven by increases in the canal command area and a proliferation of tubewells. Today, agriculture contributes around 30% to provincial GDP, accounting for 97 percent of total water use in Balochistan[2] and employs nearly two-thirds of its labor force[3]. The contributions of various sectors to AgGDP include livestock (40%), followed by fruit (30%), field crops (17%), vegetables (12%), and fisheries (1%). Water intensive horticulture crops, such as apples, still dominate the agriculture landscape. In spite of growing demand because increasing population of the province, 88% increase between 1998 and 2017 versus 57% in Pakistan[4], growth in AgGDP has not kept pace. Yields for vegetable and fruit declined over time.[5] Higher dependency on agriculture has been made possible because of spread of tubewells across the province, primarily because of government subsidies, which has increased groundwater usage for agriculture by 120% between 1996 to 2017.[6]

Balochistan is considered the fruit basket of the country. Out of the total geographic area of 34.7 million hectares of Balochistan, hardly 2.07 million (5.9 percent) is cultivated and 54 percent is currently fallow due to lack of water**.** Besides, there are 4.85 million hectares of cultural wasteland which can be brought under cultivation subject to the availability of water. Although the total cropped area of Balochistan is just 3.7 percent of the total cropped area of the country (23.45 mha), the province is the largest contributor to the national production of apples (82 percent), peaches (69 percent), grapes (97.6 percent), pomegranates (82 percent), dates (64 percent), almonds (93.5 percent) and plums (49 percent). Of the canal irrigated area, about 84 percent is in Nasirabad Division alone, which is nearly 5 percent of the province, while 6.8 percent is in Makran Division, 4.7 percent is in Kalat Division, 3.9 percent in Sibi Division and negligible in Quetta and Zhob Divisions. Thus, tubewells are the major source of irrigation outside the canal irrigated areas followed by *karezes*, springs, wells etc.

2.1 Water Availability

Situated outside the monsoon region, Balochistan has an arid climate characterized by irregular rainfall.[3] Three major sources of water for the province include: Indus Basin Irrigation System (IBIS) as per 1991 Water Accord (3.870 MAF) mainly available to Naseerabad and Jaffarabad, floodwater (*sailaba*) providing another 12 MAF, and ground water including springs, open surface wells and *karezes* (0.870 MAF). Groundwater in Balochistan is present in both confined and unconfined aquifers in all river basins and sub-basins and generally flows from catchment boundaries to the axis of the valleys. It largely follows the general trend of surface drainage and is found in the alluvial fans and piedmont plains. Halcrow Pakistan reassessed groundwater resources of 14 of 18 basins and estimated in 2015 the total annual potential was 1,071 million cubic meters (or about the total value of 0.87 MAF listed above).[7]

[3] Only 7-8 districts out of 32 districts of Balochistan fall in Monsoon zone including parts of Zhob, Sherani, Musakhel, Barkhan, Lasbela, JhalMagsi, Naseerabad, and Jaffarabad.

2.2 Water Rights in Balochistan

Water rights in the province vary among ethnic groups including , Baloch, Pashtun, and Brahvis, as per customary tribal laws. While ethnic groups face no restrictions on pumping groundwater for domestic purposes and for taking care of livestock, water rights differ for irrigation purposes. While Pashtuns recognize the rights of all along surface stream or river, Baloch and Brahvis do not recognize the water users' rights in the central and coastal areas. Local communities representing various tribes act as water managers and make their own decisions based on agreed sharing of common resources.[8] Various mechanisms to assign water rights to users are followed, particularly for small irrigation schemes using surface water. Under one methodology, water rights are assigned before the participation in an irrigation scheme. In this methodology, the rights are based upon the shareholder's ability to contribute to the investment for the construction or maintenance of the irrigation system. For irrigation schemes constructed with the help of external donors or the government, water rights are defined after construction of the irrigation system and are usually transferrable.[9]

In case of *karezs,* the Pashtuns believe that ownership of water rights depends on ownership of the mother well and therefore, the mechanisms to transport water must pass through the owner's land. For Balochs and Brahvis, Karez water is owned by several users based on their land contribution for the construction of Karez. In the Baloch dominated coastal areas, Karez water is recognized as a common property and all, who provide land for the construction of Karez, can use water according to their investment share without any compensation.[10]

The law for pumping of groundwater through tubewells remains the same across different ethnic groups. As tubewells are owned by individuals, the right to tap the groundwater also belongs to the tubewell owner. If multiple individuals contribute to the installation of a tubewell, water is shared among all depending on their investment share. Selling of water rights in also practiced among these tribes and the water charges vary from place to place , according to the crops and irrigation requirements.

2.3 History of Groundwater Development in Balochistan

Groundwater, which accounts for 4 percent of Balochistan's water resources, is the most intensely utilized water resource in the province. The history of groundwater development in Balochistan is summarized below:[11]

i. *Karezes* and Springs remained the major source of irrigation (60%) during early to mid-20th century.

ii. Rural electrification in some parts of the province in early 1970s led to increasing replacement of animal driven water lifting (Persian Wheel) with electric tubewells, which created a substantial increase in cropped area and a shift from subsistence to more commercialized cropping pattern with high valued crops.

iii. The Government implemented several donor assisted groundwater development projects (Kuwait Fund, Asian Development Bank (ADB) and World Bank (WB)) during 1980-1990, which increased the number of tubewells extracting groundwater for agriculture.

iv. Increase in number of tubewells continued during 1990-2000 because of rural electrification and subsidized electricity for tubewells. However, the installation of new tubewells was banned in Quetta sub-basin in 1995 but hardly implemented.

v. The Government, while approving the Integrated Water Management Policy in 2005, decided that: (a) subsidy would be available only to tubewells operational before January 1, 2005; (b) a new framework and system would be notified for approving subsidies on new and replacement tubewells; (c) a survey would be conducted to determine the subsidy on eligible tubewells; and (d) savings would be invested in efficient water usage schemes. However, these decisions were never implemented.

vi. Prolonged droughts (1998 to 2002 and 2009 to 2017) and overdraft of some aquifers resulted in drying up of many tubewells dispossessing many farmers access to water and consequently, livelihood.

3 Scope of the Study

This study addresses the following key questions:

(i) Is solarization of electric tubewells in Balochistan a viable and sustainable option given the current groundwater depletion and water distress situation?

(ii) What should be the technical, regulatory and enforcement mechanism to ensure that Balochistan's water economy is not running dry in case answer to (i) is in affirmative?

(iii) What are the policy options available to the Government in case answer to (i) is in negative?

4 Research Methodology

An integrated research methodology has been adopted to assess the economic and environmental viability of SETs in Balochistan. It includes findings from the existing literature, secondary data, collection of primary data during field visits to different districts of Balochistan, discussions with farmers and meetings with experts and influencers.

To gain technical insight on groundwater management in Pakistan, in particularly Balochistan and SETs, IFPRI-Pakistan's team met with various federal and provincial organizations' senior functionaries including Pakistan Council of Research in Water Resources (PCRWR), Pakistan Agriculture Research Council (PARC), the Departments of Agriculture (DoAg), Departments of Irrigation (DoI) and Department of Energy (DoE) of GoBalochistan, the Quetta Electric Supply Company (QESCO), and farmers' associations such as Zamindar Action Committee (ZAC)**.** Based on these meetings, field visits and interviews, a stakeholders' analysis matrix has been developed to reflect the opinions and arguments of these stakeholders.

To understand farmers' issues, needs and their acceptability to new technology, IFPRI's Research team also visited 3 districts in Northern Balochistan, viz. Pishin, Killa Saifullah, and Quetta, and interacted with farmers. A questionnaire was developed and with the support of On-Farm Water Management (OFWM) Wing of DoAg, GoBalochistan, 25 farmers (tubewells owners only) were interviewed to gain insights into farmers' perceptions and other significant ground realities, including farm and village level characteristics, tubewell specifications and operations, existing irrigation practices, and farmers' awareness about water scarcity and conservation measures, among other aspects.

Apart from analyzing the primary data gathered by IFPRI's team during field visits, the study also reviews secondary data on groundwater levels and annual depletion rates to understand the impact of installing solar tube wells in Balochistan. Furthermore, the report evaluates the electricity subsidies data along with financial reports, existing laws, relevant government documents, and other academic papers to provide sound recommendations.

5 Key Challenges Facing Balochistan

5.1 Recurring Droughts

Recurring drought is a major challenge in Balochistan. Balochistan experiences two types of droughts; natural droughts including meteorological and hydrological drought, and manmade droughts such as agricultural drought and socioeconomic drought.[12] Severe droughts occurring in the years 1967-69, 1971, 1973-75, 1994, 1998-2002, and 2009-2017, have led to unsustainable exploitation of groundwater in Balochistan.[13] Currently, half of the districts in Balochistan have witnessed moderate to extreme drought conditions and approximately 4.4 million people in the province have been affected by these adverse conditions[14].

5.2 Over-Exploitation of Groundwater

Tubewell proliferation and over-exploitation of water for agriculture and other usages has triggered the following issues:

i) **The tubewells subsidy has reached an unsustainable level**: The subsidy on agricultural tubewells has increased to PKR 23 billion (US$139 million) annually,[4] which is now beyond the capacity of both the federal and provincial governments because of financial constraints and the binding agreement with the International Monetary Fund (IMF)'s on-going Extended Financing Facility (EFF) approved in July 2019 to phase out subsidies on electricity.

[4] @PKR830,000 per tubewell per annum for 28,088 tube-wells

ii) **Allocation for electricity subsidy surpasses agriculture development allocation:** The government allocated PKR 21 billion (US$126.5 million) for agriculture development during the last five years cumulatively, PKR 4 billion (US$ 24.1 million) annually, while allocation for subsidy on agricultural tubewells each year is PKR 23 billion (US$139 million).[15] This skewed budgetary allocation towards subsidies is posing a burden on the government as well as on society and the environment.

iii) **Groundwater overdraft in the province has reached distressing level[5] and is threatening the sustainable agriculture and livelihoods**. Data from various sources shows that the water table in the province is depleting at an alarming rate of 30-40 feet per year and, in certain places, farmers are mining ir-rechargeable "fossil" water[16].

iv) **Exhaustion of Sub-basins:** 10 out of 18 sub-basins of the province are exhausted [17], particularly in the Quetta valley and Pishin-Lora basin, where the water table has declined to 1,200 feet.

v) **Loss of social and economic opportunities:** Due to an absence of effective regulation and weak enforcement of existing law, poor recharge mechanisms, and recurring droughts, groundwater overdraft is now impacting the social and economic opportunities for the population It is leading to drying up of traditional *karezes*, springs, loss of agricultural activities, deteriorating water quality and land subsidence (gradual sinking of ground).

vi) **Disincentivizing farmers to conserve water:** Presently, farmers do not have any incentive to conserve water. They are encouraged in the form of subsidy provided by the government to pump more water. It seems that the subsidy on electric tubewells for agriculture is adversely affecting the water economy of Balochistan. Additionally, in absence of regulation and monitoring, farmers across the province have been installing illegal tubewell connections to extract groundwater.

vii) **Lack of awareness regarding vitality of water:** There is lack of awareness amongst the general public as well as the government regarding critical situation of water in the province, and the need for its conservation and effective management of groundwater.

6 Politics of Tubewells in Balochistan

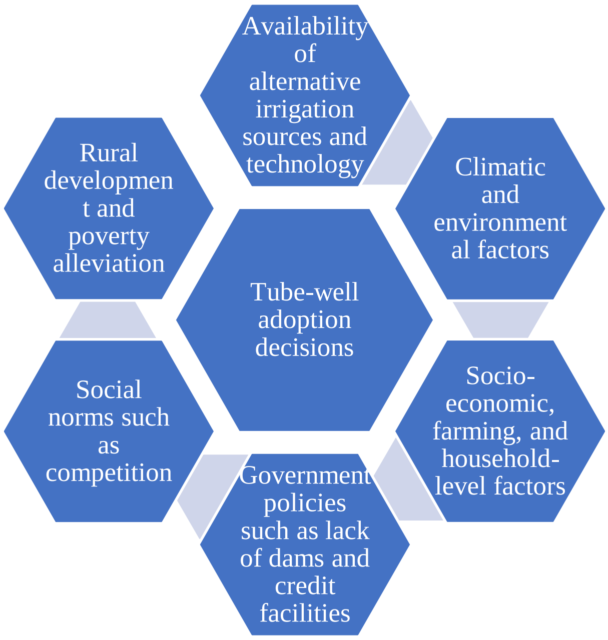
6.1 Key Drivers of Tubewells Adoption in Balochistan

The use of tubewells for agricultural and domestic purposes has become a way of life in Balochistan in recent years, replacing the more traditional and sustainable sources of groundwater extraction. The arid province with scanty rainfall depends heavily on

[5] Groundwater overdraft occurs when groundwater use exceeds the amount of recharge into an aquifer, which leads to a decline in groundwater level

groundwater resources for agriculture. Based on several studies, the key drivers identified for rapid adoption of tubewells in Balochistan are summarized at **Figure 1.** These include climatic and environmental factors; socio-economic farm and household factors such as farm size, income, cropping patterns and intensity; government policies including access to credit and substantial subsidies; rainfall, groundwater availability and topography; and the availability of alternative irrigation sources[18]. The decision to install a tubewell to access groundwater for irrigation also depends on village-level characteristics such as population density, the extent of rural development, market access, availability of electricity and cropping intensity.

Figure 1: Drivers for Tubewells Adoption



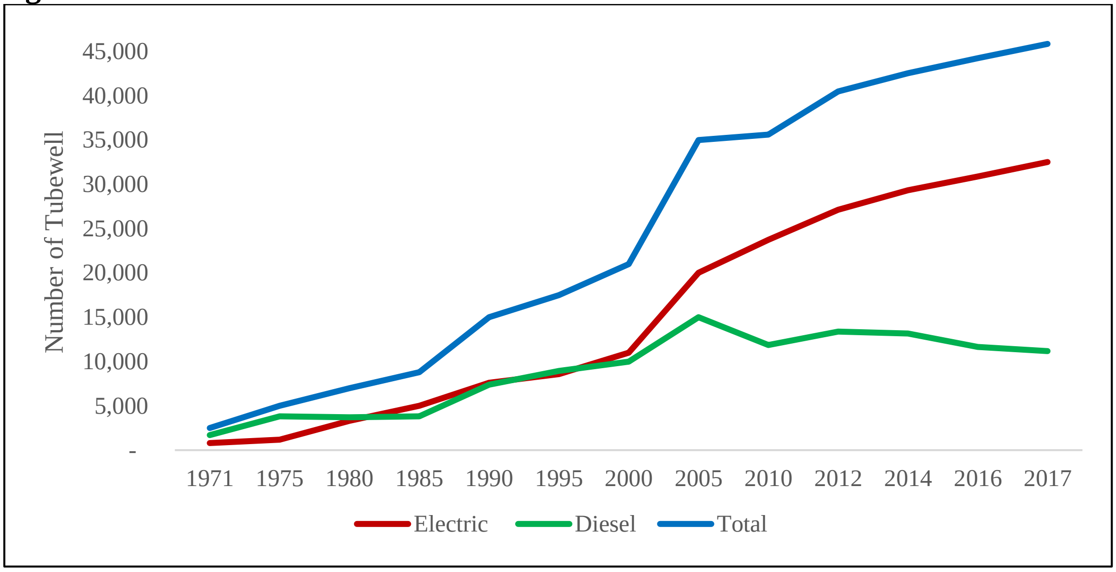
Source: Authors' research and Khair et al. (2015)

Khair et al. (2015)[19] **explored farmers' perceptions of the drivers of tubewell adoption in Balochistan**. Using results from a survey conducted on 279 farmers in 18 basins, the study employs a logit econometric model to highlight the factors that led to the surge in electric tubewells in the province. Significant and positive impacts on tubewells includes the provision of electricity subsidy, access to credit, limited availability of alternative irrigation sources, and the household's income . IFPRI team's analysis is consistent with these findings. Variables such as the age and educational status of the household head, family size, farm area and access to repair and maintenance facilities, which are believed to impact farmers' decisions to adopt tubewells, were found to have no effect on the decisions to install electric tubewells.[20]

6.2 Growth of Tubewells in Balochistan

The extraction of groundwater in Balochistan started in 1960s, when diesel and electric tubewells were introduced by the government. Rural electrification since the 1970s and the subsidy are main drivers behind the sharp increase in electric tubewells.[21] Apart from this, government development schemes and donor funded projects like the installation of free or subsidized tubewells, or the provision of interest free loans for this purpose also encouraged the adoption of electric tubewells.[22] The Pakistan Machinery Census reported an overall annual growth of 6.5% in tube-wells in Balochistan, with the inventory rising to approximately 45,836, including 30,387 electric tubewells in 2018. Of these electric installations, 1,483 receive electricity from K-Electric and the remaining from QESCO[23]. **Figure 2** shows the growth in tubewells installed in Balochistan for selected years from 1971 to 2018. The total includes STs installed after 2014, with 2156 solar tubewells installed in 2017.

Figure 2: Growth of Tubewells in Balochistan

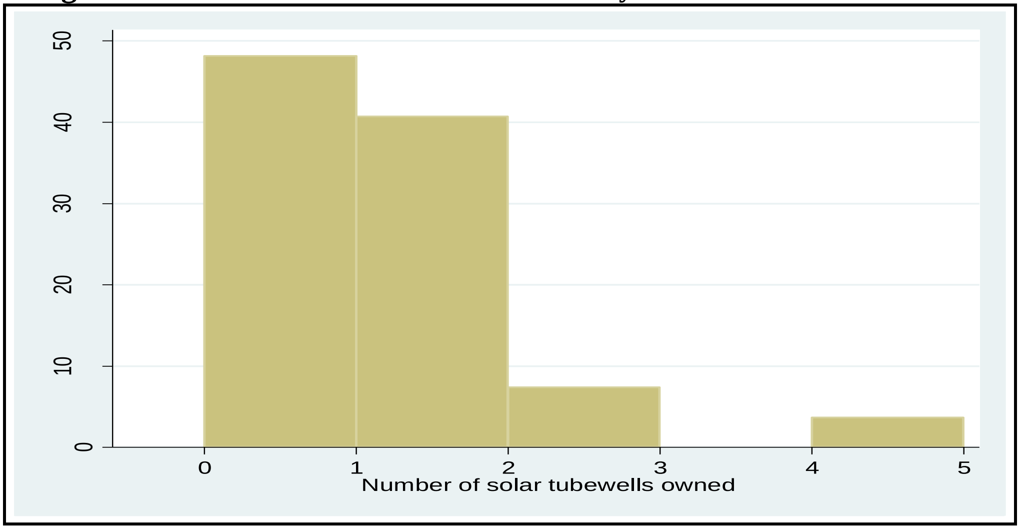


Source: Agriculture Statistics, Government of Balochistan (Various issues)

6.3 Solar Tubewells Trend

The field study undertaken by IFPRI in the three districts of Northern Balochistan was not only useful in assessing key drivers of tube-well adoption but also highlighted significant aspects of the operation and maintenance of tube-wells owned by farmers. Among the 25 farmers interviewed, 60% farmers were large, with land-holding between 45 to 200 acres. The field visits revealed that, on average, farmers owned more than one tube-well, as only 3 farmers among the 25 interviewed reported to have installed just one electric pump. **Close to 89% of the farmers interviewed (25) already owned solar tubewells for irrigation purposes and others showed a willingness to shift to solar tubewells** (see **Figure 3).** The main reasons for this shift are long load-shedding hours, voltage fluctuations which damage the submersible motor pumps, and high maintenance costs, making the electric tubewells less beneficial now, even with extensive subsidies on electricity. Conversely, solar tubewells have an initial capital cost, low operation and maintenance costs and provide uninterrupted power supply, which enables farmers to irrigate as and when needed. It helps in increasing their agriculture produce and improve their profit.

Figure 3: Number of Solar Tubewell Owned by Farmers

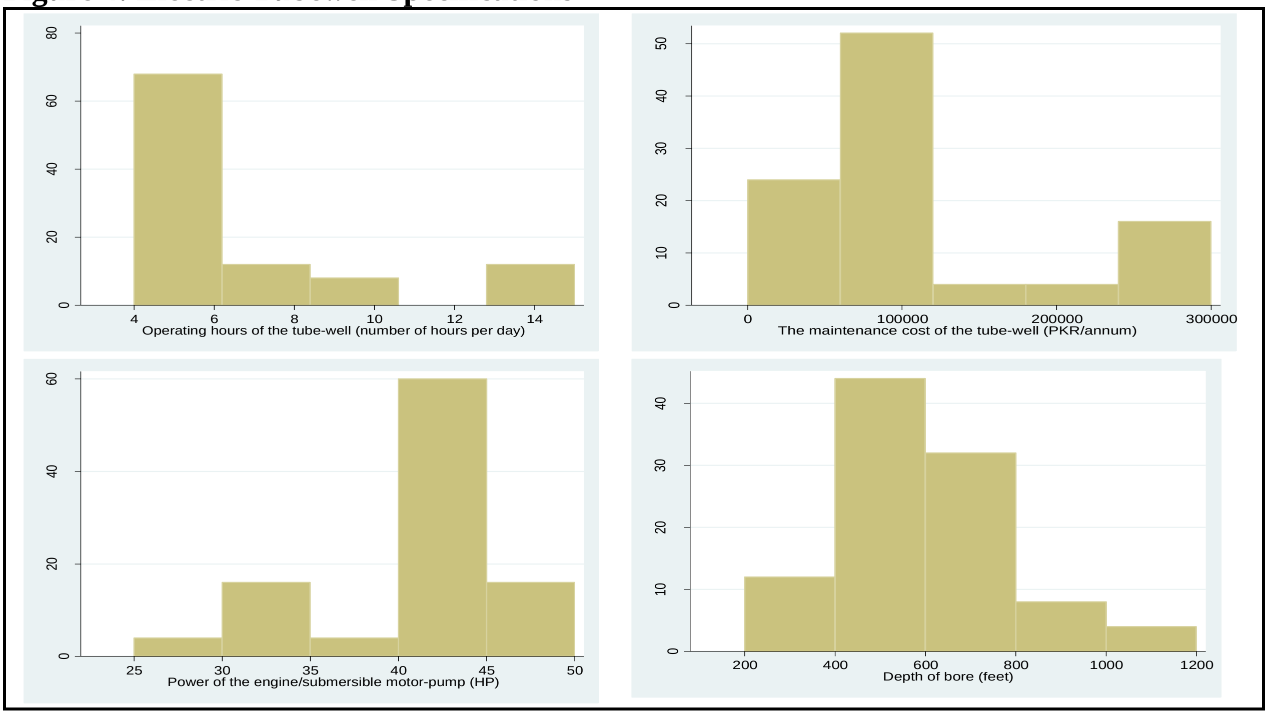


Source: IFPRI meeting with farmers, November 4-8, 2019

6.3.1 Characteristics and Specifications of Tubewells

Figure 4 below summarizes the key tubewell specifications that were reported by the farmers interviewed by IFPRI team. The figure below reveals that farmers in the province have installed motors ranging between 40-50 HP, owing to rapidly lowering water tables. Operating hours of these tubewells depend on the availability of electricity. About 74% of farmers claimed that they operated the tubewell for 6-8 hours per day when electricity is available. The average maintenance and repair cost reported by farmers was approximately PKR 109,720 per annum, as the submersible pump requires maintenance 2-3 times per year.

Figure 4: Electric Tubewell Specifications



Source: IFPRI meeting with farmers, November 4-8, 2019

6.4 Illegal Connections for Tubewells

There has been a surge in the number of installed electric tubewells, with the number almost doubling between 2007 to 2017[24] because of the on-going energy crisis in Balochistan to abstract sufficient water when electricity is available only 6-8 hours per day because of load shedding, more tubewells are required. During the field visits, the team observed installation of illegal electric tubewells. Approximately 21,000 illegal electric tubewells have been reported in Balochistan, with 5,000 illegal tubewells in the district of Pishin alone[25]. The pervasiveness of illegal tubewells across the province was confirmed during the interactions with farmers, as a majority had more than one tubewell installed but just pay QESCO for one electric connection[26]. This trend was further substantiated by the presence of private market for electric transformers, where farmers can ask technicians/mechanics to manufacture transformers per their specifications. For example, a 100 Kilowatt (kW) transformer is available for PKR 60,000[27]. These transformers are then used to energize illegal connections for tubewells through the same feeders that supply electricity to legal connections for tubewells.

Major drivers of illegal tubewells, as identified by relevant stakeholders, are long load shedding hours, fluctuating voltages, and depleting aquifers.[28] These are installed to make-up for the loss of water abstraction because of load shedding. It is estimated that most large farmers have installed, on average, more than one tubewell (in some cases three to five, including private STs, which make up for the quantity that could be extracted when electricity is available for longer hours. The functionaries of the Department of Irrigation (DoI) opined that the private sector and farmers are responsible for non-compliance with the procedures in the Balochistan Groundwater Rights Administration Ordinance; additionally, QESCO has failed to take punitive action against these illegal connections thereby letting the number rise.[29] QESCO, on the other hand, asserted that monitoring of these illegal connections is difficult as farmers install such transformers and tubewells inside their premises and local tribal customs and traditions restrain them from entering their premises. However, informally learnt that these farmers allegedly seemed to be paying “speed money” to staff to avoid legal action, perhaps negating this argument.

6.5 Limitations

It may be added here that while interaction with farmers and key stakeholders in Balochistan provided invaluable insights, the limitation is that the data could be collected from three districts of Northern Balochistan while using a small sample. With these limits acknowledged, the above findings can be generalized to the whole of Balochistan for policy recommendations, though with caution because of cultural and topographical differences in Southern Balochistan. Moreover, the non-availability of groundwater data, as the DoI lacks a real-time, district-wise, monitoring mechanism for aquifer usage and depletion over time. Therefore, a further reliance on secondary data is needed to analyze the water situation in the province.

7 Subsidy for Agriculture Tubewells

Favourable public sector policies of the provincial government including water sector development, improvement in technology and subsidized electricity for agriculture stimulated the spread of electric tubewells and the use of groundwater in the province. While the strategy has achieved some prominent successes in expanding cultivated area, increases in yield and in promoting high value agriculture, it has contributed to massive groundwater resource exploitation and excessive mining of water. The government encouraged farmers to install tubewells for agriculture in the province through: (i) development projects for tubewells on a cost-sharing basis (ii) interest-free loans and (iii) a substantial subsidy on electricity consumption.

Nevertheless, the subsidy regime has been under criticism for quite some time because of (a) huge financial implications (b) equity issue and (c) adverse impact on groundwater.

7.1 Financial Implication of Subsidy for Agricultural Tubewells

Initially, tubewell owners were required to pay 50% of the bill and the government picked up the remaining 50%. During late 1990s, this subsidy was increased to 90% following demonstrations by farmers in the province. The government rationalized the subsidy and decided to provide a flat rate tariff of @PKR 4000 per month on electric tubewells for agriculture from July 2001, while the remaining amount was shared in the ratio of 40:30:30 by the federal government, provincial government and WAPDA/QESCO **respectively.** This arrangement continued till June 30, 2010. The subsidy was withdrawn w.e.f. July 1, 2010 and normal meter-based billing was restored.[30] The farmers, however, continued to pay PKR 4,000 per month. Following farmers' agitation and political pressure, the federal government was compelled to restore electric tubewells subsidy effective from December 1, 2012 at a revised formula, with the consumer paying @PKR 6000, and additionally any amounts above PKR 50,000 (non-subsidized) per month, with the federal and provincial governments sharing 40% and 60% of the differential (PKR44,000) respectively. However, decision on liability accrued during the intervening period between July 1, 2010 to November 30, 2012 is still pending.[31]

With 28,088 operational electric tubewells and an annual subsidy of PKR 830,000 (US$5,000) per tubewell,[32] the gross annual subsidy has now reached to PKR 23 billion (US$139 million). Due to low revenue recovery from agricultural consumers[33], QESCO arrears accrued to PKR 267 (US$ 1.609) billion in March 2019[34]. Standing guidelines allows a maximum engine size of submersible pump up to 30 HP (22.37 kWh); eight hours uninterrupted electricity supply from QESCO (30 days per month), and electricity tariff rate is fixed at PKR 14 per kWh[35]. Since these tubewells are without meters, there is no account of units of electricity consumed, which has been a source of continuous conflict. While the Department of Energy is of the view that, based on standing terms and conditions, the annual electricity bill should be around PKR 20 billion (US$120.5 million), QESCO claims it to be around PKR 55 billion (US$331 million).[36] Farmers and QESCO are in continuous dispute as to authenticity of the billing.[37]

7.2 Equity Issue

There is a consensus amongst researchers that the subsidy on electric tubewells for agriculture is benefiting a small fraction of farmers. Ashraf and Sheikh (2017) argue that only 0.3% of the population receives direct benefit from this subsidy, while PIDE estimated that the existing electric tubewells account for less than 4% of the total electricity connections in the province but consume 80% of the available electricity[6]. 91% of the subsidy payment for the electricity bill is untargeted, as half of the land area irrigated through electric tubewells belongs to just 15% of farmers.[38] Memon (2019)[39] finds that this subsidy only benefits 15 percent of farmers in Balochistan which raises equity concerns.

7.3 Groundwater Depletion Trend

Ground water is a common pool resource for the province and, in the absence of regulation and group organization, is most likely to suffer from the "Tragedy of the Commons". Direct consequences of this market failure include over-exploitation, water table depletion, greater extraction costs and drying up of the resource.[40] A report of the Islamic Relief Pakistan (2018)[41] depicts a situation of drought and excessive groundwater depletion in Chagai, Noshki, Kharan and Washuk districts**.** The study highlighted an annual average decline in the water table of around 7 meters (23 feet) in the four selected districts. It also notes that the overall rate of water table decline is 30-40 feet per annum in the province, and in the Quetta-Pishin basin, ground water has been over-abstracted and currently ir-rechargeable "fossil" water is being mined. Similarly, empirical results from a survey of 279 farmers during 2009 in highland Balochistan showed that ground water resources have been exploited at an unsustainable rate, lowering the water table by 2 to 5 meters (7 to 16 feet) per annum in Pishin, Loralai, Killa Saifullah, and Killa Abdullah[42]. Farmers in our sample from Quetta, Pishin and Killa Saifullah reported an annual decline of 20 to 50 feet per annum in 2019.

The data provided by the DoI, GoBalochistan demonstrates that average depth of tubewells between 2000-2018 reached 550 ft, with the greatest depth recorded in Mastung at 930 ft, followed by Quetta at 830 ft. The situation is alarming considering that 20 out of 22 districts (except Lasbela and Gawadar) have tubewell depths greater than 400 feet (*see* **Figure 5)**.

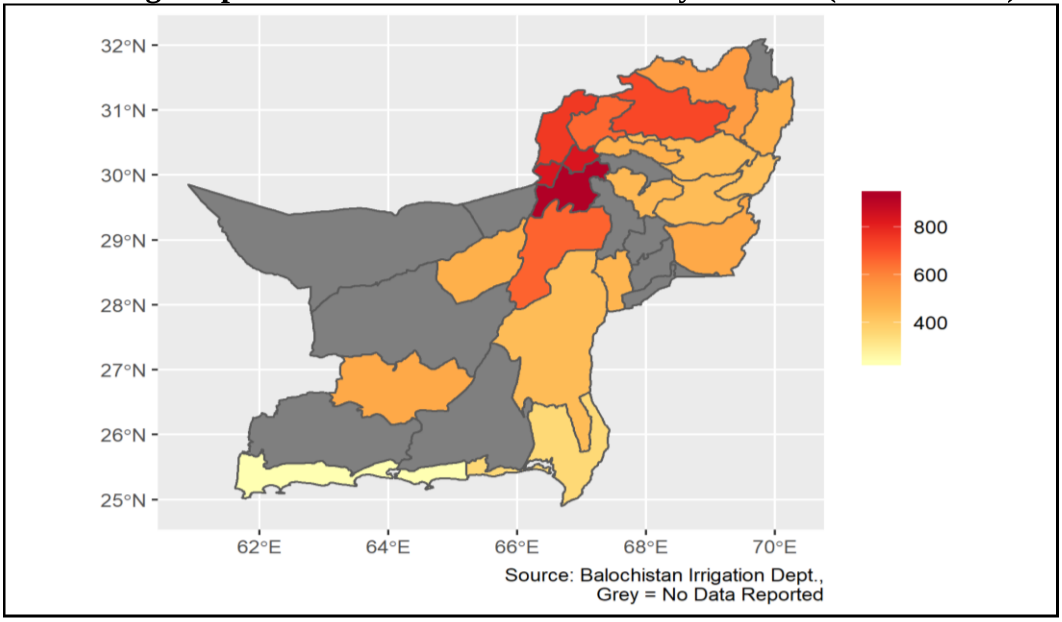
7.4 Causes of Groundwater Depletion

As highlighted above, the higher rate of groundwater depletion in Balochistan is caused by: (i) scant rains and recurring drought during the last three decades, with consequent dependence on groundwater for agriculture, livestock and domestic purposes; (ii) proliferation of tubewells, encouraged by favourable government policies, to extract ground water; (iii) expansion in cultivated area and promotion of water intensive high delta crops; (iv) practice of

[6] Farmers blame that QESCO parks its distribution losses and theft to consumption of electricity by tubewells while QESCO argue that farmers have installed pumps of more than 30HP, not permissible under the policy and own more than one tubewells including illegal connections. However, as mentioned earlier, since these tubewells are operating without meters, there is a high probability that QESCO might be overcharging the farmers.

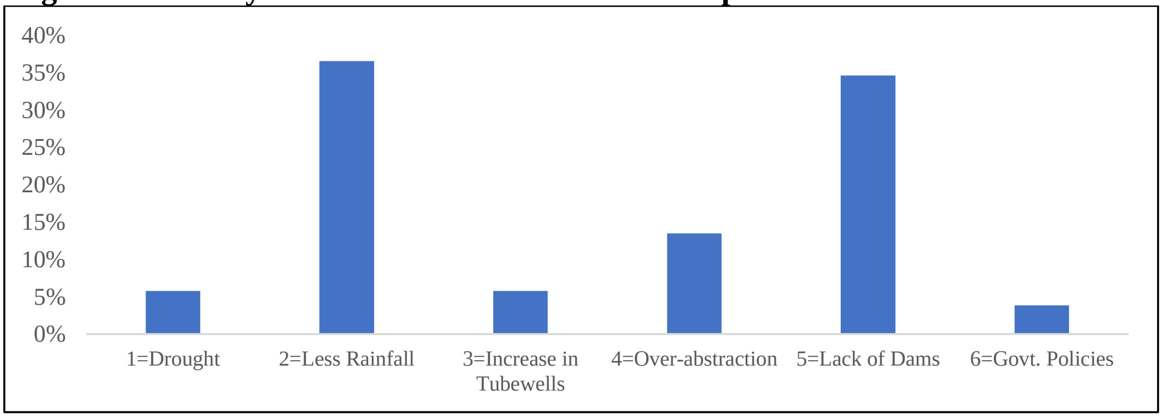
flood irrigation; (v) weak infrastructure for water storage such as dams, check dams, leaky dams, etc.; and (vi) lack of awareness amongst the general populace regarding water conservation. These causes are supported by a large body of literature[43], interaction with stakeholders during field trip of IFPRI's team,[44] the Drought Assessment Report for Balochistan by Islamic Relief Pakistan[45], Ashraf and Majeed (2000)[46], and substantiated by Khair et al. (2019)'s survey wherein farmers were asked to rank the main reasons for groundwater decline.[47]

Figure 4: Average Depth of Tubewells in Balochistan by Districts (2000 to 2018)



Source: Irrigation Department, Government of Balochistan

Figure 5: Primary Reasons for the Groundwater Depletion



Source: IFPRI team meeting with farmers during field visit to Balochistan, November 4-8, 2019

Contrary to above findings, farmers in our sample do not consider the rise in number of tubewells as the primary reason for groundwater depletion; rather they see absence of dams and low rainfall as the main drivers for this challenge. Figure 6 shows that only 13% of the farmers considered over-abstraction, while 6% noted the increased tubewells to be the primary reasons for water depletion. Most of the farmers interviewed understand that water scarcity in the province is a severe issue, but they are still practicing flood irrigation.[48] It is generally believed that solar-tubewells, because of its longer operation and low operational and maintenance cost, will accelerate the process of groundwater depletion[49].

7.5. Existing Irrigation Practices and farm productivity

Ideally, the rising cost of groundwater extraction, combined with energy shortages, should have encouraged the farmers to switch to water saving agricultural and irrigation practices. Nevertheless, flood irrigation remains the most common irrigation method in the province. Agriculture in Balochistan, whether irrigated or *Sailaba*, uses too much water as farmers are indifferent to the social cost of water. For example, farmers use over 2,400 mm of water against a requirement of 1200 mm for apples.[50] Failure to irrigate crops according to their water requirements has not only added a burden on the already stressed water resources but has also lowered crop yields and quality. Balochistan's water productivity for many crops is less than national average. Average yield of apples is less than both national and world averages,[51] (*see* ***Table 1).***

Table 1: Yield of Fruits (Tons/Hectare)

Fruits	Balochistan	Pakistan
Grapes	4.48	4.47
Almonds	2.05	2.12
Apple	6.61	6.83
Apricot	6.96	6.64
Pomegranate	4.64	5.11
Plums	6.78	7.66
Dates	3.39	5.50
Peach	2.97	4.99
Pears	2.50	8.94
Banana	10.64	4.49

Source: Agriculture Statistics 2017-18, MNFSR, Government of Pakistan.

While the GoBalochistan has invested in canal lining and construction of pools to store water, the financial crunch has constrained a scaling up effort. Secondly, donor funded pilot projects to introduce high efficiency irrigation system (HEIS) have not yielded the desired results. Therefore, farmers are reluctant to invest in drip systems in absence of incentives.[52]

7.6. Shifting to High Value Water Intensive Crops

Increase in Tubewells at an annual rate of 6.50% since 1970,[53] **with associated growth in cultivated area of** fruit orchards by 6%, from 35,700 ha in 1985–86 to 211,800 ha in 2017-18.[54] Higher profits (*See* **Table 2)** encouraged farmers to switch to high-valued, water-intensive fruits and vegetables such as apples, which provided "significantly higher potential returns (four to five times) per unit of land from apple farming compared to grain crops it displaced."[55] The adverse impact of this proliferation of Tubewells is discussed *supra*.

Table 2: Expenditure and Income on Agricultural Tubewell in Balochistan *(values per 15-20 acres)*

No.	Item	Expenditure (PKR)	Income (PKR)	Net Income (PKR)
1	Electricity	72,000	0	-72,000
2	O & M Cost	50,000	0	-50,000
3	Apricot	295,800	435,000	139,200
4	Vegetables	21,727	108,635	86,908
5	Apple	112,446	299,857	187,410
6	Wheat	51,138	306,825	255,688

Note: Average farm size per TW is 6–8 ha (15–20 acres)

7.1.1 7.7 Lack of Awareness for Water Conservation

Farmers in our sample survey had knowledge of drip irrigation technology, but only one farmer seemed to be using it. Likewise, 70% of the farmers interviewed were aware of efficient water management practices, but only 11% adopted these practices in the selected districts. For example, 95% of the farmers interviewed were using flood irrigation. Regarding rainwater conservation, only 27% of farmers in the sample reported to have adopted methods to save rainwater. These factors reflect an indifferent attitude towards conserving groundwater and using water efficient practices. It requires strengthening the capacity of the Directorate of OFWM and enhancing awareness of the farmers and general public to achieve sustainable groundwater.

7.8 Lack of Adoption of High-efficiency Irrigation Systems (HEIS)

Balochistan is ideal for HEIS due to high evapotranspiration rates, rapid groundwater depletion and growth of water-intensive high-value crops[56]. The adoption of modern water-savings technologies has remained low in the province. This can be attributed to (i) lack of finance[57], (ii) flat-rate electricity tariff for electric tubewells to extract groundwater, (iii) lack of proper incentives to encourage irrigation efficiency (iv) non-availability of local material and lack of technical know-how to adopt complicated design, (v) absence of backup support for maintenance and repair, and (vi) small sized landholdings, which have been major impediments in adopting HEIS in Balochistan[58]. While farmers showed their willingness to adopt drip irrigation on cost-sharing basis, it is important to develop local market for technical support and availability of accessories to promote HEIS.[59]

It is often argued that providing STs with drip irrigation can encourage water conservation at the farm level. Most stakeholders and experts recommended drip irrigation with STs to avoid over-exploitation of groundwater[60]. However, evidence shows that introducing drip irrigation alone does not necessarily encourage water savings as it can lead to increase in cropping area, cropping intensity, or shift to water-intensive crops (Scheierling, et. al., 2014). Therefore, for successful conservation, farmers' attitudes towards this technology need to be altered to promote water efficiency in Balochistan. IFPRI's work in Punjab showed that farmers who were willing to adopt subsidized drip irrigation aspired to increase their cropping area and switch to high-value crops such as fruits and vegetables[61] (Bell, et. Al., 2020). Besides improving farmers' access to water saving technologies, demonstrating the profitability of water saving technologies is also important. Creating a civic sense among farmers regarding the value of water practices conservation and accepting it as a social responsibility is imperative (i.e. a structure to reflect a common pool resource). Appropriate pricing of groundwater, where farmers pay for the true value of resource, can also be useful in discouraging farmers for inefficient use of water.

7.9 Impact of Over-exploitation of Groundwater

To sum-up, the continuous groundwater depletion is impacting the individual as well as aggregate levels. Some of the most common effects include:

(i) **Decline in agricultural production:** Some of the affected farmers have uprooted their apple orchards due to declining water tables[62].

(ii) **Loss of Livelihood:** Farmers are losing livelihoods and are migrating in search of alternative income sources.

(iii) **Land subsidence:** Using GPS data, Kakar et al. (2016)[63] find that Quetta Valley is sinking by 30mm/y in the periphery to 120 mm/y in the city centre. Land surface elevation changes can cause damage to infrastructure including, buildings, roads, bridges, and pipelines. Aquifer depletion can also lead to surface cracks (Bouwer, 1997)[64].

(iv) **Deterioration of Water Quality:** As water table reaches unsustainably low-levels, natural and manmade pollutants tend to concentrate at the bottom, making water unsuitable for drinking and irrigation. As reported by IUCN (2000) Balochistan, drinking samples from groundwater in Quetta were reported to have high concentrations of nitrate, sulfate, arsenic, selenium, chromium and nickel[65]. These pollutants in drinking water pose a risk to public health that can further lower the social and economic well-being of people of Balochistan.

(v) **Emergence of Informal Water Markets**: Rapid groundwater depletion in Balochistan has led to the emergence of unregulated informal groundwater markets allowing water trading in exchange of payment or crops[66]. As tubewells dry up, farmers, searching for a reliable source of water for crops, are accessing these markets to buy groundwater or buying it from neighboring tubewell owners.[67] The water sellers in these markets are mostly farmers with surplus water or non-agricultural businessmen. However, these water markets are small and fragmented.

(vi) **Emergence of "Tanker Mafia" and Increasing Social Inequality:** Non-availability of drinking water due to drying up of aquifers and water shortages in Balochistan has also given rise to a "tanker mafia" to supply water for domestic purposes.[68] In Quetta alone, approximately 200 privately owned tankers operate illegally and supply groundwater to households, charging PKR 1,500-2,500 per tanker.[69] The severity of the water crisis in the recent past has further increased households' dependence on these providers. This has added a burden on low income households, exacerbating existing inequalities. It has also caused people to move from place to place in search of neighborhoods with lower water tanker prices[70]. Incidentally, there are no arrangements in place to check this illegal activity.

8 Legal and Institutional Regime

8.1 Groundwater Regulation

The Balochistan Groundwater Rights Administration Ordinance, promulgated in 1978 and then amended in 2001, regulates "the use of groundwater and administer the rights of the various persons therein". The Ordinance (i) requires registration of existing groundwater extraction points; (ii) establishes procedure and development of location-specific rules agreed by the main local stakeholders; and (iii) issuance of permits for an indefinite period under these rules for the development of new *karezes*, dug wells and tubewells through District Water Committees comprising government officials and two local notables. These Committees before granting permit are expected to hear objections from the surrounding landowners. Appeal can be made to the Divisional Commissioner and the Provincial Water Board. The Provincial Water Board is also tasked to formulate policies on groundwater withdrawal, such as, estimating safe yields, existing level of withdrawal, and administering all water points.

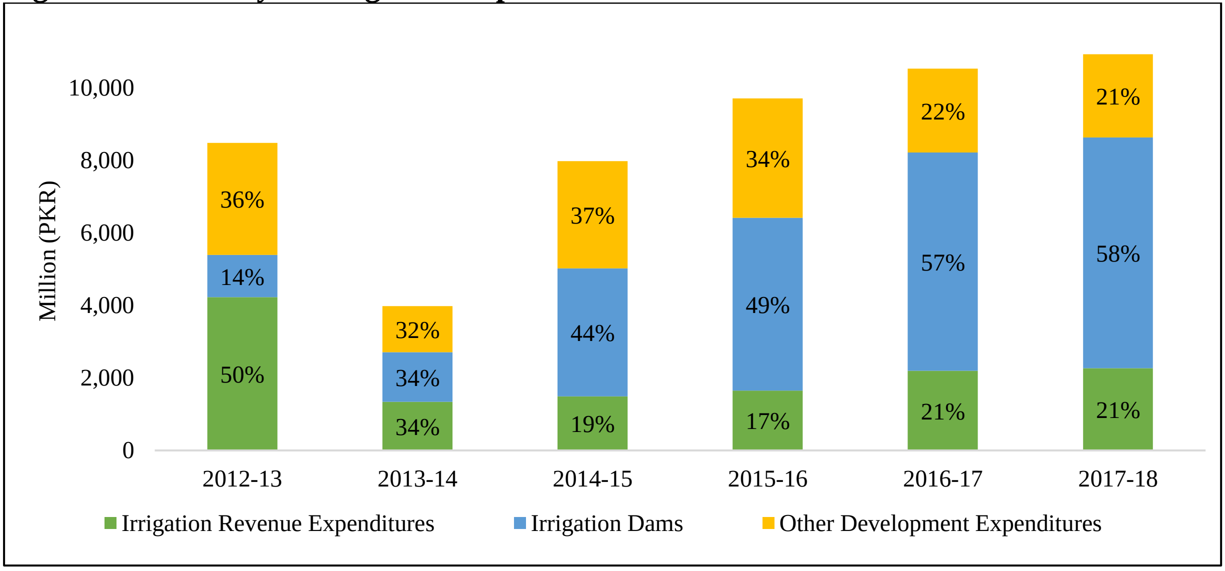
The Ordinance provides a framework for local groundwater resource management through the local administration and the tribal elders, but it was not complemented by local rules which are yet to be framed. The only local rule issued under this Ordinance was a total ban on new wells in Quetta Valley in 1990 with the intention to safeguard the drinking water supply. Consequently, instead of location specific locally agreed rules, a standard minimum distance [250 meters of the first well in case of soft land (alluvium) and 500 meters in case of hard land (hard rock)] rule (Harim rule) was adopted through amendment in 2001. However, this rule was applied only in a few cases.

While the Ordinance lays proper guidelines for groundwater management, its failure to involve local communities in managing groundwater resources is its biggest shortcoming[71]. The Ordinance also fails to provide guidelines to address and control groundwater over-draft. Due to its cumbersome implementation procedures, the Ordinance has largely remained ineffective and uncertain, which is allowing over-extraction of groundwater with impunity.

8.2 Role of Department of Irrigation (DoI)

The DoI, GoBalochistan is responsible for planning, investigation, design, and implementation of various water development projects. It aims to harness scarce water resources to enhance agricultural productivity by monitoring, collecting and compiling ground and surface water data, and by constructing and maintaining irrigation facilities[72]. An analysis of the development budget of DoI **(***see* ***Figure 7)*** reveals that while a significant proportion of the budget has been spent on construction and restoration of dams, including delay action dams and check dams[73], collection of groundwater data and prevention of over-extraction of groundwater in the province is weak. Non-availability of required equipment and gadgets, such as water meters, piezometers and water gauges as well as limited capacity of the human resource constrains DoI's ability to monitor water tables across the province.[74] Institutional reforms are needed to revamp the department and strengthen its involvement in the Provincial Water Board and district-level water committees[75]. An institutional review is needed to assess the weaknesses of the department and its human resources, and to recommend policy measures that are needed to transform the existing institution for effective management of water resources of the province.[76]

Figure 6: Summary of Irrigation Expenditures



Source: Financial Statements of the Government of Balochistan, Controller General of Accounts (Various issues)

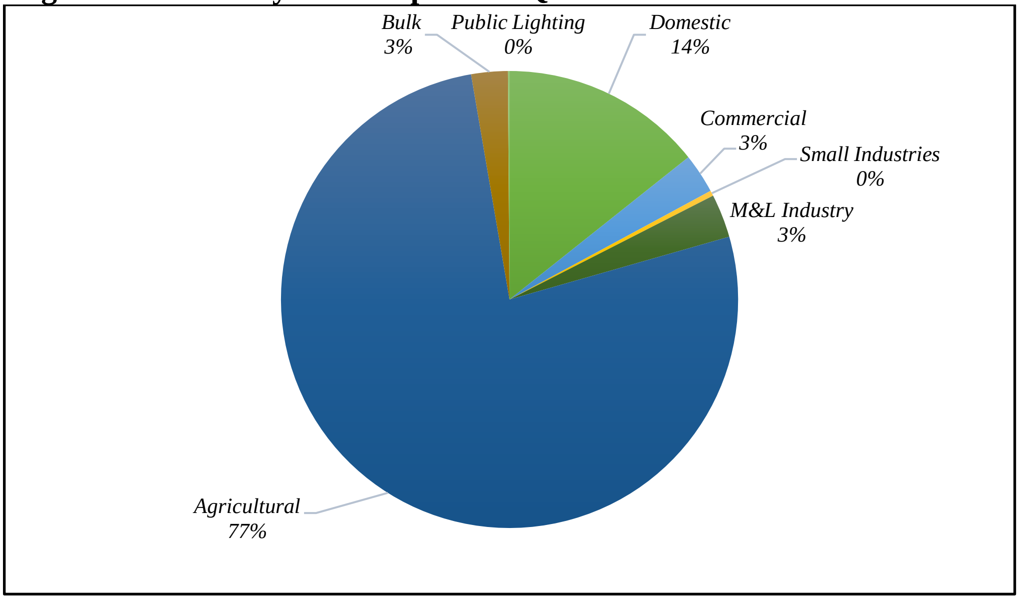
8.3 Role of Department of Agriculture (DoAg)

The primary functions of the Agriculture Department include conducting agricultural research and extension services, developing agriculture methods for enhancing productivity and preventing plant diseases, overseeing marketing committees and regional markets, and undertaking agriculture surveys and several other agriculture-related activities[77]. With moderate capacity of the human resource and limited resources, the Directorate of On Farm Water Management (OFWM) is making efforts to cope with emerging challenges, in particular the depleting water resources in the province. It is important to strengthen agriculture research and build the capacity of Agriculture Extension workers (supposedly the change agents) by equipping them with current knowledge and modern agriculture practices, which enable them to educate farmers to raise their awareness about water conservation and to see the benefits of switching to high-value, low delta and water efficient crops. Additionally, the provincial government needs to rationalize existing expenditures and create a fiscal space to enhance investment in the agriculture sector, including irrigation.

8.4 Quetta Electric Supply Company (QESCO)

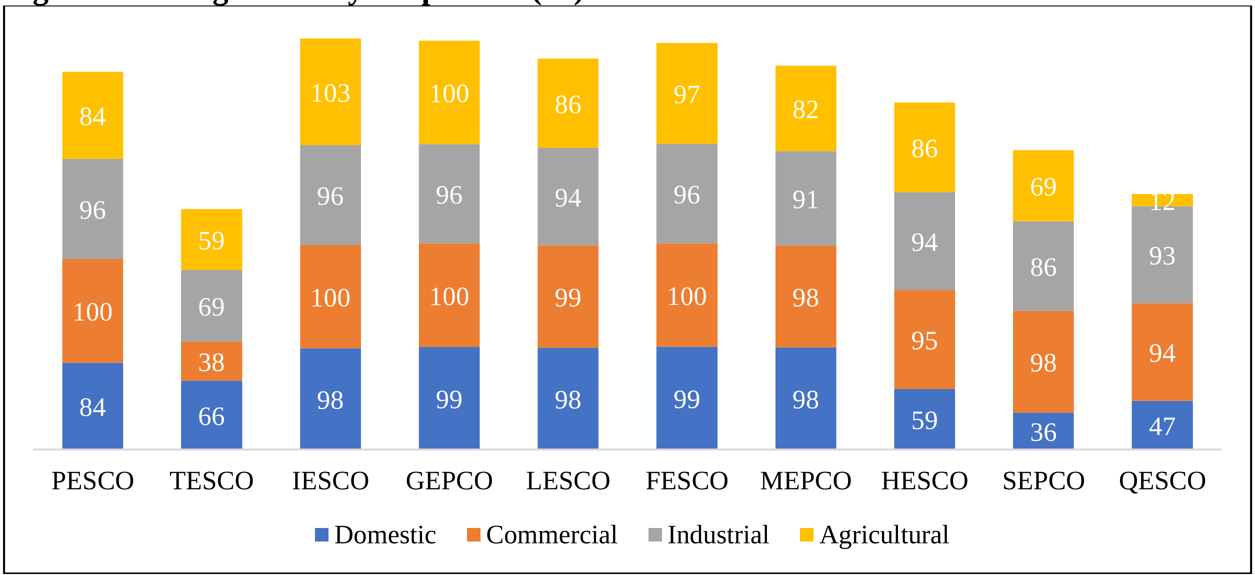
QESCO, formed in 1998, covers a service area of 334,616 square kilometers in Balochistan[7] **with 591,552 electricity consumers**, 75% of which are domestic consumers, 19% commercial, 5% agriculture tubewell owners, and 1% includes small and large industry and others. 70-80% of the total electricity demand in QESCO area comes from tubewells owners. **Figure 8** provides electricity consumption by economic groups, with agriculture being the largest consumer because of subsidy. Other DISCOs typically have highest consumption by domestic consumers, with agriculture use only at 10%.

Figure 7: Electricity Consumption in QESCO



Source: Power System Statistics, 2017-18, National Transmission & Dispatch Company

Figure 8: Billing Recovery Proportion (%) of Main Economic Sectors of DISCOs



Source: State of Industry Report, 2018, National Electric Power Regulatory Authority (NEPRA).

[7] Service area includes whole Province of Balochistan, except Lasbela connected with K-Electric.

QESCO transmission and distribution losses (32%) are the highest among all DISCOs, while line losses are 22%. QESCO's revenue recovery declined to 25% of the billed amount in 2017-18 with 12% in agriculture sector *(see **Figure 9**)*.High transmission and distribution as well as line losses, inefficient collection of receivables, low revenue recovery and declining gross profit margin leads to long hours of load shedding**.** QESCO rely heavily on the subsidy towards its total revenues that it receives from the federal and provincial governments for electric tubewells for agriculture.[78] Net of subsidy, the financial position of QESCO may be unsustainable.

The key financial ratios of QESCO for FY2009 to FY2018 are in Table 3. The gross profit margin (revenue – cost of goods sold) declined from 34% in 2009 to negative 6% in 2013, then rose to 22% in 2017 before decreasing again to 5%. The current ratio (current assets/current liabilities) remained below 1, except in 2014, showing a difficulty in discharging short-term obligations. The average collection period for receivables is very high reflecting weaknesses in revenue recovery. Finally, the Table shows that the percentage share of the subsidy in the total revenue of QESCO has remained above 40% except 2013 when the government withdrew subsidy.

Table 3: QESCO Ratio Analysis

	2018	2017	2014	2013	2010	2009
Gross Profit Margin	5%	22%	29%	-6%	26%	34%
Percentage share of subsidy in the revenue	43%	49%	38%	0%	41%	42%
Current Ratio	0.64	0.72	1.17	0.75	0.57	0.48
Debtors Turnover	0.82	1.11	0.88	0.66	2.06	4.56
Average Collection Period/Days Sales Outstanding (DSO)	448	328	414	551	178	80
Creditor's Turnover	5.65	5.50	7.52	8.22	60.34	99.36
Assets Turnover	7.04	1.92	0.44	0.46	-3.51	-3.26
Shareholder Equity (PKR Million)	-135,453	-106,423	-16,939	-25,025	-23,004	-20,270
Debt to Equity Ratio	-2.08	-2.20	-9.32	-7.33	-3.80	-3.22
Debt to Total Assets Ratio	1.31	1.20	0.55	0.76	1.36	1.45

Note: Financial Data was not available for the financial years of 2016, 2015 and 2012.
Source: Annual Financial Statements, QESCO, (Various issues)

9 Stakeholder Analysis for Solarization of Electric Tubewells

9.1 Raison D'etre of Solarization of Electric Tubewells

The *raison d'etre* of the federal and Balochistan governments' intention to switch 28,088 electric tubewells to solar power in Balochistan is: (i) ensuring an off-grid power supply to agriculturists at affordable price in far flung areas of Balochistan; (ii) phasing-out flat-rate tariff and subsidy of PKR 23 billion to reduce burden on national and provincial exchequer; (iii) saving 900 MW of electricity which would be enough to meet the shortfall of Balochistan which is approximately 850 MW; (iv) reducing operation and maintenance cost; and (v) addressing the issue of unpaid bills and revenue loss to QESCO. Notwithstanding these benefits, a major drawback of this scheme is that it would have negative impact on depleting groundwater resource in Balochistan.

Agriculture in Balochistan largely relies on *Karezes*, springs, and deep dug tubewells. However, the exponential rise in tubewells over the last four decades is now stressing water tables in the province. Limited availability of surface canal irrigation, with Kirthar, Patfeeder and Kachhi Canals irrigating 5% of Balochistan's total land, and wastage of 85% of rainwater because of lack of storage capacity and poor conservation practices, further complicates situation for rainfed agriculture. Continuous energy crisis worsens the situation as each farmer on average needs three to five additional tubewells to extract the same quantity of water in 4-6 hours that they extracted with one tubewell over 10 to 15 hours with adequate availability of electricity.

In this backdrop of water crisis like situation, solarization of tubewells in Balochistan is raising red flags. Prolonged droughts and depleting groundwater have already triggered issues of social equity. Small farmers and landless labourers have suffered the most as they lacked resources to to dig deeper to meet water requirements and thus, are moving out of the business. It is feared that a cheap and uninterrupted power supply for tubewells would accelerate the groundwater abstraction and expedite exhaustion of fresh groundwater basins, which would not only deepen the social inequity but also result in intergenerational equity issues. The short-term gain of the present generation would be at the expense of future generation threatening their food, livelihood and human security.[79]

9.2 Stakeholders Analysis

The following stakeholder analysis regarding the SETs project has been undertaken with a consideration of the following dimensions: 'Importance' (which describes a particular stakeholder's interest in the project), 'view' (which presents their opinions about the proposed SETs project), and 'influence' (which provides an insight regarding stakeholder's relative power to influence the project).

Box 1. List of Stakeholders for SETs

The following are the main stakeholders interested in the solarization of tubewells in Balochistan:

Policy Making and Supervisory Institutions:
Government of Balochistan, Ministry of Finance, Ministry of Power and Planning Commission, Government of Pakistan Economic Coordination Committee of the Cabinet (ECC), National Water Coordination Committee, Finance Department of Government of Balochistan

Regulatory Institutions: National Electric Power Regulatory Authority (NEPRA)

Ancillary Actors: Alternate Energy Development Board, Ministry of Science and Technology (Pakistan Council of Research in Water Resources), PARC, Balochistan Departments of Energy, Irrigation, and Agriculture (Agriculture Extension and On Farm Water Management)

Public Sector Entities: Quetta Electric Supply Company (QESCO)

Development Partners and Lenders: Potentially World Bank and Asian Development Bank

Academic Institutions: Pakistan Institute of Development Economics, Balochistan University of Information Technology, Engineering and Management Sciences (BUITEM)

Civil Society and Consumer Groups: Zamindar Action Committee (ZAC) comprising large farmers, Small Farmers,

The list of relevant stakeholders is at Box 1. Figure 10 represents their comparative influence in decision **making. Figure 11** represents stakeholders' analysis matrix. The Stakeholders' Position Matrix is at **Table 4.**

Figure 9: Influence of Various Stakeholders

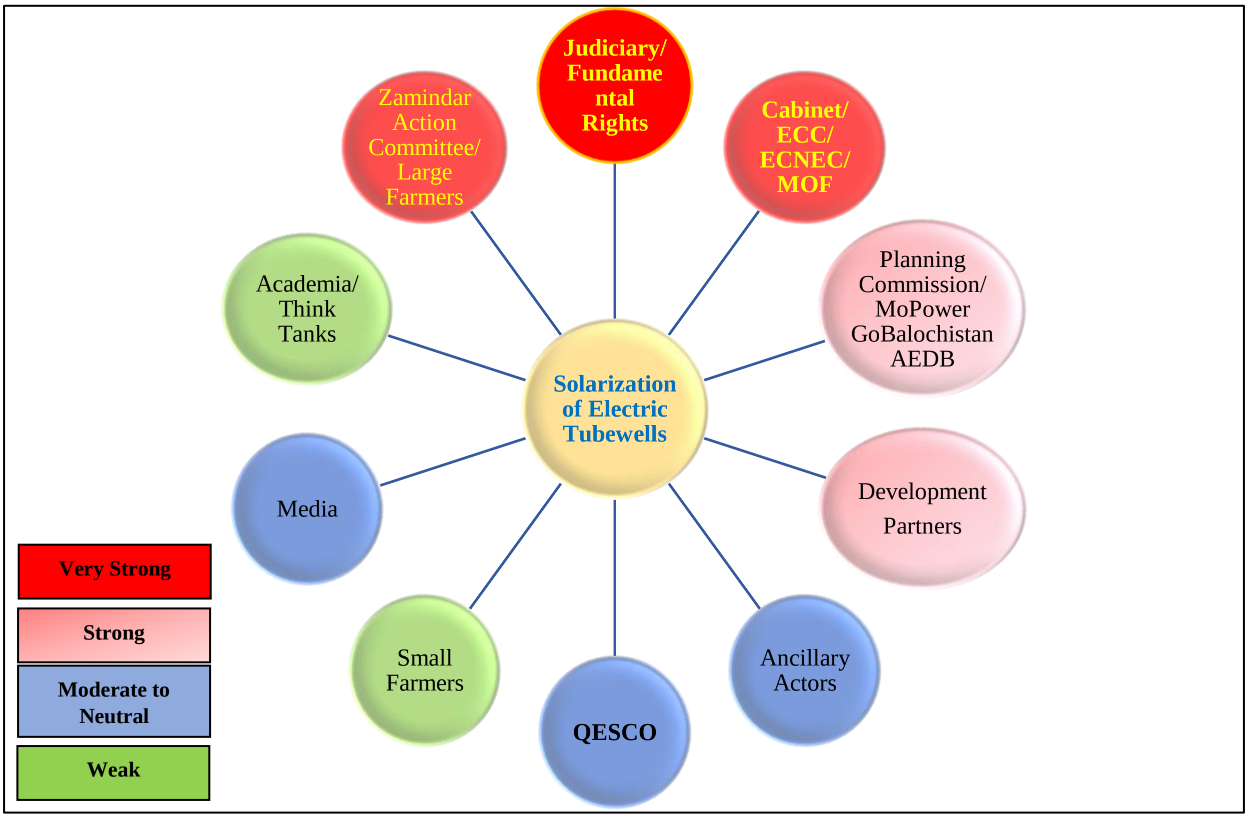


Figure 10: Stakeholder Analysis Matrix for Solar tubewell Project

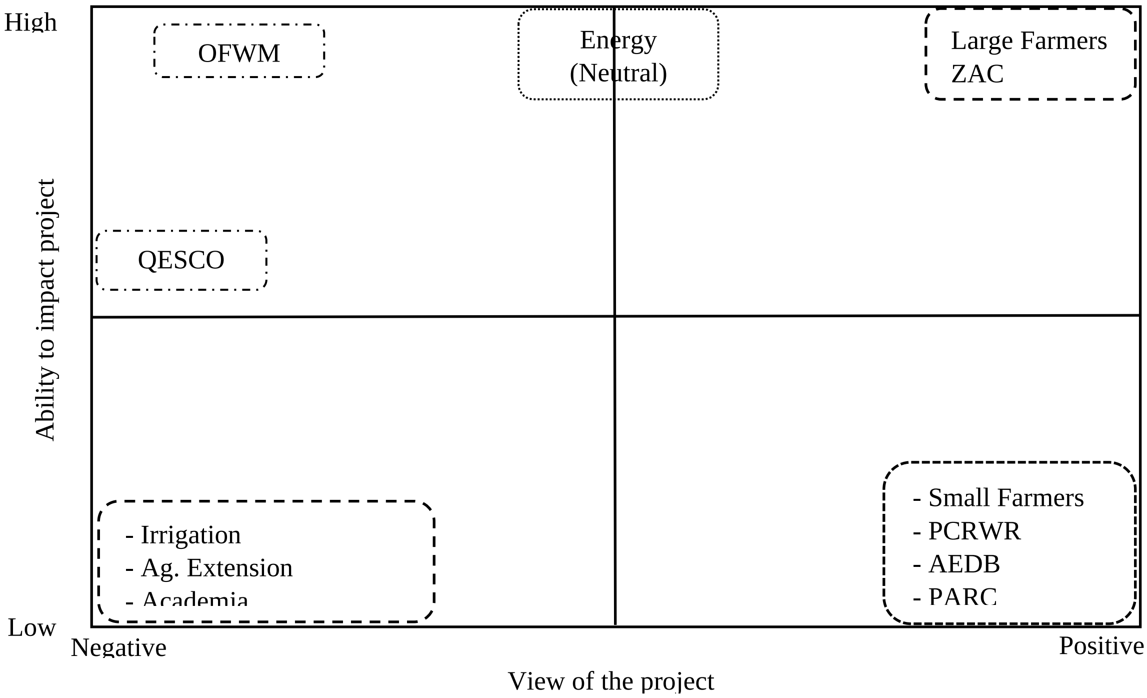


Table 4: Stakeholders' Analysis

Stakeholder Category	Relevant Stakeholder	Responsibility of Stakeholder	Importance of Stakeholder	Interest in Reform	Influence	Stakeholder's Position on the Proposal
Government Policy Making and Supervisory Institutions	Ministry of Finance	Key Player in Fiscal and Monetary Policy and Donors' assistance; Manages National Finance Commission, Revenue Collection, and Budget allocation for all Ministries	Key Ministry that regulates division of resources amongst provinces, debt management, allocation of resources and Co-sharer of Tubewell subsidy	Strong, especially to phase out federal share in subsidy for Tubewells for Agriculture in Balochistan	Very Strong	Will support any reform that can absolve the Federal Government of current subsidy
	Ministry of Power	Drafting Power Policies, including Hydro, Agreements on Reform packages with Donors, Managing GENCOs, CPPA, NTDC, DISCOs & their privatization, IPPs, RPPs and CPPs Policy, Implementation of Power Policy and monitoring power system	Key Forum chaired by the PM and includes MOF, MOWP, MPNR restricting itself to periodic review of power supply position, circular debt and tariff	Significant, as it can save 850 MW of electricity and also reduce transmission and revenue losses of QESCO, likely to follow ECC/ECNEC decision	Strong	Will support any proposal that could save electricity and improve QESCO's financial position.
	Planning Commission	Responsible for national development plans, allocation of resources for development schemes and reforms	Key Ministry for planning, development and reform	Strong; it provided the initial feasibility study	Significant	Will largely depend on technical feasibility, political direction and ECNEC's decision
	Economic Committee of the Cabinet	Key Policy Forum for decisions on all economic issues including tariffs, taxes, power and gas tariffs	Significant, chaired by the Finance Minister/Advisor to PM for Finance	Very Strong, it can remove/reduce subsidy share of the Federal Government in Tubewells for Ag	Strong influence. Wields huge formal & informal authority for pushing reform agenda	Will be interested in a viable financial cum political solution if it still requires some form of subsidy
	Government of Balochistan	Management of Provincial Affairs	Significant	Moderate	Strong.	Has been Advocating SETs
	Finance Department	Management of Provincial Financial Resources	Limited to political directions	Muted; abolishing provincial subsidy	Limited	Interested in reducing Tubewells subsidy. Will follow political directions

Stakeholder Category	Relevant Stakeholder	Responsibility of Stakeholder	Importance of Stakeholder	Interest in Reform	Influence	Stakeholder's Position on the Proposal
Regulatory Institutions	NEPRA	Responsible for regulating power and electricity tariffs	Key institution to determine tariff and surcharges, enforcing better governance, and measures to control theft	Muted	Limited to determining tariff	Latent.
Ancillary Actors/ Implementing Agencies	Department of Irrigation, Balochistan	Responsible for management of water resources and enforcement of Balochistan Ground Water Rights Administration Ordinance (BGWRA) Ordinance, 1978, construction of water storages	Significant	Significant	Moderate to neutral Will follow the political direction	Strongly believe that the proposed project will further deplete groundwater tables because of expected over-abstraction. Proposes to construct surface water storages
	Department of Agriculture, Balochistan	Responsible for Agriculture Sector in Balochistan. The On-Farm Water Management Directorate along with Agriculture Extension are responsible for introducing high efficiency irrigation technology, water conservation, tunnel farming and low-delta crops	Medium	Significant	Moderate	Believe that the proposed project will be cost-ineffective beyond 300-400 ft depth, aggravate worsening depleting groundwater tables. If SETs are considered important, must accompany an effective monitoring and enforcement mechanisms
	Department of Energy, Balochistan	Management of energy resources in the province, responsible for matters relating to electricity	Key department to deal with electricity bills	Significant because of perpetual dispute on electricity billing by QESCO and the process of reconciliation	Moderate	It supports the project for sole objective of eliminating subsidy as well as to get rid of over-billing. It has reservation about sustainability of the project in view of depleting aquifers similar pilot project in Kharan failed.

Stakeholder Category	Relevant Stakeholder	Responsibility of Stakeholder	Importance of Stakeholder	Interest in Reform	Influence	Stakeholder's Position on the Proposal
	QESCO	Manage electricity supply in Balochistan including electric tubewells	Significant	Muted because of loss of subsidy	Moderate to neutral	Suspicious about sustainability of the project, fear that farmers are likely to continue with both electric and solar tubewells due to illegal connection, does not support net metering
	PCRWR	Research on water issues	Medium	Significant	Moderate	Supports the project as it holds the view that STs can extract water only for 5-6 hours contrary to general perception. It proposed to combine it with recharge mechanisms such as leaky dams, inverted wells, delay action dams to check over-exploitation of groundwater
	AEDB	To promote alternate energy resources in Pakistan	Significant	Significant	Medium to strong	Sponsoring the project and supports it to develop renewable energy resources
Beneficiaries	Zamindar Action Committee	Represents medium to large and politically influential farmers	Significant	Weak	Very Strong	Supports the project. They negate the perception that SETs will lead to over abstraction of water & worsen groundwater situation
	Small Farmers	Unorganized	Weak	Neutral	Weak	High initial capital cost is beyond their financial capacity and are willing to continue with the existing system

Stakeholder Category	Relevant Stakeholder	Responsibility of Stakeholder	Importance of Stakeholder	Interest in Reform	Influence	Stakeholder's Position on the Proposal
Academic Institutions,	PIDE	Do survey based empirical research and modeling on public policy issues	Medium as the linkage between academic and policy process is not very strong	Significant	Limited. PIDE has produced policy briefs on the subject	Defenders but wants it to be combined with net metering and monitoring mechanisms
	Academia and Researchers	Empirical and qualitative research on public policy issues	Medium	Significant	Weak	Opposed to the proposed project. Proposes technical study to assess impact on water tables and investment in creating alternate economic opportunities, small commercial farms, low delta crops, tunnel farming, adopting high-efficiency irrigation systems, development of recharge mechanisms, pricing water at its true cost
Development Partners	WB, ADB	Funding large thermal and hydro projects that are strategically important for the economic and social development of Pakistan.	Significant as most power sector projects including transmission are donors driven	Significant in power sector reforms since 1992 and continuing till date	Strong.	Will be guided by technical feasibility, social and environmental safeguards policies of the institutions. May suggest that the project be accompanied by a reform package if they, at all, consider the project for support
Media	Express Tribune, Dawn, Daily Times	Highlighting weaknesses in the system, projecting policy flaws and holding governments accountable	Significant	Strong	Muted so far but can influence based on strong findings	Latent so far

9.3 Primary Stakeholders

Farmers: The ZAC strongly supports the project as they consider that ST extract less water compared to electric tubewells and would promote water conservation in Balochistan. However, high initial capital costs keeps small farmers from installing STs and support the existing subsidized electric tubewells in the province[80].

Irrigation department: The DoI believes that the proposed project would aggravate the depletion of groundwater tables because of over abstraction. The DoI underlined the need for strict adherence to the Balochistan Ground Water Rights Administration Ordinance (BGWRA) Ordinance, 1978, and the development of an effective monitoring system for enforcement of the Ordinance, construction of dams, development of recharge mechanisms, and banned use of tubewells to resolve the groundwater crisis in the province. The DoI can be effectively engaged in the project provided the provincial government formulates an investment plan to construct dams, develop recharge mechanisms for groundwater, add teeth to create a transparent and equitable enforcement of BGWRA.

Agriculture Department: Directorate of OFWM believes that STs would be cost-effective up to 300-400ft; beyond this depth, these would also be cost-ineffective as costs rise non-linearly with depth and the Department is also concerned about its impact on already depleting groundwater. The directorate proposes that the project should only be introduced if STs are complemented with built-in monitoring mechanisms, high-efficiency irrigation systems, recharge mechanisms, and awareness campaigns to encourage water conservation by farmers. The Directorate has already promoted tunnel farming and a shift to low-delta crops, such as olives and pistachios, to reduce water usage in agriculture.

Directorate of Extension, Department of Agriculture: The Directorate subscribes to the views of the Directorate of OFWM, and desires a huge investment in recharge mechanisms, high-efficiency irrigation systems, mini dams, and awareness campaigns for water conservation practices. It can be engaged constructively in outreach to farmers for awareness and training in water conservation practices, as well as introducing high efficiency technology.

Energy Department: The DoE supports the project, as they see an opportunity to phase out the huge subsidy on electric tubewells. However, they require a demonstration of technical feasibility. They also have reservations about the sustainability of the project in view of depleting aquifers, as a similar pilot project in Kharan failed. In that project, about 142 tubewells were converted from electricity to Solar power at a cost of PKR 200 million[81] but the efficiency of the STs declined due to continuous water depletion. Therefore, unless remedial measures are taken to address the severe challenge of depleting groundwater, their view is that the ST technology is likely to fail. As an implementation department, the DoE would be engaged in planning, designing, and execution of the project and can influence the project.

QESCO: QESCO has serious concerns about success of the project. It believes that in the presence of 21,000 illegal connections, farmers are likely to continue with both solar and electric tubewells. Even the separation of domestic and agriculture feeders would not succeed. The Company is also skeptical about the success of net metering options for STs. In the eventuality of approval of the project by the federal government, QESCO would be responsible for converting electricity from 3-phase to two/single phase connections to ensure farmers do not use electric tubewells post SETs, but given its enforcement capacity, it seems a remote possibility. Also, it would lose a major source of revenue from the subsidy which might trigger financial challenges for it.[82] It would also make it more challenging for QESCO to recover its outstanding arrears of PKR 267 billion from agriculture consumers (PKR 211.52 billion), the provincial government (PKR 27 billion), and federal government (PKR 28.48 billion).[83]

9.4 Non-Farm Water Users

The non-farm water users who use water for drinking, domestic purposes, and other economic activities such as industries, livestock, etc. have not been consulted for the proposed SETs project. They are likely to be the worst affected in case of further depletion of groundwater with the implementation of SETs project without adequate protection.

9.5 Secondary Stakeholders

Academia and Researchers: Well informed academics and researchers who have undertaken many studies about the evolving surface and groundwater situation in Balochistan are strongly opposed to the proposed project. Their concerns are regarding a lack of detailed study on the likely impact of the project and absence of consultative process, and a strong possibility that further over-abstraction of groundwater will aggravate the water crisis further. Some of them also believe that farming in Balochistan is only profitable due to the subsidy on tubewells for agriculture. In the absence of this subsidy, farming may not be a profitable venture because of high water extraction cost in the province. They suggest that the government, instead of financing SETs, should invest in creating alternate economic opportunities and jobs, promotion of small commercial farms, a movement to low delta crops, adopting high-efficiency irrigation systems and tunnel farming, development of recharge mechanisms, pricing water at its true cost to discourage its rampant and unchecked use and intense awareness campaigns.

Pakistan Institute of Development Economics (PIDE): PIDE is supporting the SETs project. They argue that the myth that Pakistani farmers are technology averse and adhere to traditions is unfounded, as they adopted modern pumps decades ago, and are are very much open to adopt any technology that is concordance to their needs. Therefore, solar operated pumps may be welcome in Balochistan due to their affordability and the energy security that they offer. However, one cannot expect them to conserve water if it is not making any difference in their disposable incomes.[84] They feel that the farmers may be more responsive to net-metering but shifting to such a new regime would need a HEIS with strong monitoring mechanisms to prevent further decline of water tables.

Pakistan Council of Research in Water Resources (PCRWR): PCRWR strongly favored the SETs in Balochistan as the project would help by saving billions of rupees of annual subsidy, reduce water extraction, as it thinks STs can only extract water for a maximum of 5-6 hours per day in summer and 2-3 hours in winter and would reduce the social disparity created by the subsidy. The department however, proposed development of recharge mechanisms such as leaky dams, inverted wells, delay actions dams to check over-exploitation of groundwater in the province.

Pakistan Agriculture Research Council (PARC): PARC strongly favored SETs in Balochistan, as it believes that it will reduce the average water extraction hours. However, PARC noted that SETs would work best when combined with High-Efficiency Irrigation System (drip and sprinkler technology), switching to less water-intensive crops, provision of reverse metering and awareness campaigns to encourage behavioral change among farmers.

Alternate Energy Development Board (AEDB): AEDB not only supports the SETs project in Balochistan but was engaged in design of first PC-1 for the project. The Board's support is based on the huge financial savings and the promotion of renewable energy in the province. According to them, farmers are already using solar energy systems and are aware of crop management and efficient water management practices. However, to ensure that farmers would not use both electric and STs. It suggested to replace 3 phase electric connections with 2 phase or single phase connections, which will not only be costly but can have negative implications for broader economic development

10 Cost Benefit Analysis

The Cost-benefit analysis (CBA)[85] is based on cost assessment including *capital costs, project management costs and operating and maintenance costs for STs,* and benefits assessment *(avoided bills for farmers, avoided agriculture tubewell subsidies and benefits to farmers in terms of operating cost of electric tubewells).* This assessment is done from the perspective of all stakeholders with financial interests. In addition, implicit costs including the opportunity cost of water usage *(water cost)* and the depletion cost of water *(solar inefficiency cost)* have also been included in the cost-benefit analysis as well. Indirect positive benefits include the environmental benefits gained by reduced carbon emissions and the power generated by the reduced supply of electricity to agricultural tubewells. **Life of project is assumed twenty years with discount rate of 11.53%.[8]**

10.1 Cost Assessment

The Cost of the project is estimated to be PKR 145,060 million plus Project Management Unit (PMU) cost of PKR 28.56 million annually over the project period , with an Operation and Maintenance Cost of PKR 435 million @ PKR 15,500 per tubewell per year ***(see Table 5).***

Solar Obsolescence Cost: It is the cost that farmers must bear because of the declining efficiency of STs.[86] The average annual water table decline is assumed to be 30-40 feet per annum due to excessive use of tube-well in the province[87], as we have demonstrated in section 7.3. As the water table declines, the solar power source becomes insufficient to abstract water

[8] The discount rate is the rate at which future values are discounted for government investment analyses. http://www.finance.gov.pk/circulars/circular_02122019.pdf *(accessed 14 January 2020)*

from a higher depth, and both new panels and bigger horsepower pumps are needed. Therefore, farmers would need to bear increased cost of PKR 1.5 million for the additional solar power generation and water delivery system including a new submersible pump every 3 to 4 years to keep their tube-well capable of accessing water from a greater depth efficient[88].

Table 5: Project Cost

Stage and depth	Phase	Period	Tubewells Replaced	Capital Cost (PKR Mn)	PMU Cost (PKR Mn)	O&M Cost @PKR15,500 per tubewell/per year (PKR Mn)[89]
Up to 400 feet	I	Year 1 Year 2 Year 3 Total	2,243 4.057 3,700 10,000	41,890	28.56 28.56 28.56	
Up to 600 feet	II	Year 1 Year 2 Year 3	10,000	52,520	28.56 28.56 28.56	
Up to 800 feet	III	Year 1 Year 2 Year 3	8,088	50,650	28.56 28.56 28.56	
Total		9 Years	28,088	145,060	257	435

Opportunity Cost of Water: The opportunity costs of water is given in **Table 6**, which shows a range of values for water use in agriculture, by commodity as well as for an aggregate value for Pakistan. The primary purpose is to determine a value for the cost benefit analysis and to look at increased benefits from reallocations of water to different crops. If effective water markets existed, these values would be close to the market prices.

Table 6: Water values (USD per cubic meter)

Source	Dates	Wheat	Maize	Citrus/Fruit	Potato/Vegetables	
Bierkens	2006-10	0.018	0.040	0.058	0.008	
	1991-2010	0.013	0.023	0.043	0.006	
CGE-W	2014	0.018	0.058	0.022	0.012	0.018
Average[1]		0.016	0.016	0.040	0.041	0.027

1. The averages are of the column values, including the column for aggregates.

Notes: The Bierkens Misc. is an average value for selected commodities from other literature which was summarized in the Bierkens (2019) article. The values in the average are thus across dates and countries. Details of the CGE-W values are presented at the end of Annexure-I.

Bierkens[90] and the CGE-W[91] tend to give low but similar values across commodities. In principle, the value of water could be estimated by its value in urban markets, as that source of demand will grow, and those consumers can usually afford to pay more. However, it will not be more than a 10 percent shift for several decades, and so a better measure might be the values that water has in its best use in agriculture. The various values listed in the Bierkens' studies follow the same methodology over different time periods. Except for rice, each of the values grew by 30 to 40% when the earlier and later periods are compared. The CGE-W values are computed in a very different way but tend to be similar to Bierkens values in most cases. Given that water is not easy to transfer across time and space, it is typical for different commodities to have significantly different values. Maize consistently seemed to have the highest value across studies, and probably represents the highest individual value that should be given for any agricultural commodity. The CGE-W gives an overall value, that includes major cereals in the average, and therefore it is likely to be too low for several reasons.

In Balochistan, the crops using groundwater tend to be those with higher values of water, so the values for wheat and fruits and vegetables (as valued here) are less likely to reflect the value of water in the province. Also, an overall value is needed for the cost benefit analysis, rather than individual commodity values. Balancing these considerations leads us to choose just the average of the various aggregate values, or **USD 0.018 dollars per cubic meter**. Since the project has grave consequences for water tables, ignoring the opportunity cost of water cost would provide an inaccurate picture of the project viability.

10.2 Benefit Assessment

The benefits that would accrue because of SETs include:

Avoiding Monthly Bills: The economic benefit accruing to farmers from the SETs project is to avoid monthly electricity bills. According to the current policy in Balochistan, farmers pay a flat rate of PKR 6,000 to 10,000 per month.[92]

Subsidy Savings: It is assumed that, with SETs, the government would avoid PKR 65,000 per tubewell per month in subsidy payments.[93]

Additional Power Availability: SETs would save 850-900 MW, which QESCO could sell to other sectors. Additional power benefit is computed by calculating average electricity consumption by each tubewell using a 40 HP pump for 8 hours per day on average (87,098 kWh per year). Total power benefit is assessed at the highest tariff rate of PKR 15 per kWh.[94] Sum of avoided bills and subsidy is subtracted from this total benefit to obtain additional power benefits.

Saving Operating Cost Benefit. Farmers, on average, must repair a submersible pump 4 to 5 times per year due to unstable voltage. Each time the repair cost is about PKR 20,000 or more. It is estimated that a benefit of PKR 109,720 per tubewell per year would accrue to farmers.[95]

Environment Benefit: SETs would reduce greenhouse gas emissions. Considering the power generation mix of Pakistan[96], the carbon emission rate (CER) is estimated using carbon dioxide (CO_2) emitted from furnace oil. The emission rate of CO_2 is 0.24 kg for one kWh of electricity[97]. Assuming the electricity consumption of 65,323 kWh per tubewell per year, the SETs is expected to reduce 17.11 tons of CO_2 emissions or 17.11 CER[9]. Considering one CER equals five USD[98] would lead to environmental benefit of PKR 13,264 per tubewell per year.

Results Estimates: Economic rate of return has been estimated using a discount rate of 11.53%[99] and 20 year life of the project. **Table 7** presents the results based on three scenarios:

[9] One CER is equals to 1 tonne of carbon dioxide.

- Scenario-1: Base Scenario
- Scenario-2: Capital cost of the project increases by 20 percent due to implementation delay from 9 years to 12 years, non-availability of resources and exchange rate depreciation.
- Scenario-3: Capital cost of the project increases by 40 percent due to implementation delay from 9 years to 15 years, non-availability of resources and exchange rate depreciation

Table 7: Results of Cost-Benefit Analysis (PKR Million)

Particulars	**Scenario 1**	**Scenario 2 (capital cost increases by 20%)**	**Scenario 3 (capital cost increases by 40%)**
PV of Capital Cost	93,588	112,306	131,023
PV of Project Management Unit (PMU) Cost	173	173	173
PV of Maintenance cost of STs to Farmers	2,113	2,113	2,113
PV of Solar Obsolescence Cost	59,915	59,915	59,915
PV of Water Cost	49,289	49,289	49,289
PV of Total cost	**205,078**	**223,796**	**242,513**
PV of Avoided Farmers Bill Benefit	16,436	16,436	16,436
PV of Avoided Subsidy Benefits	106,833	106,833	106,833
PV of Additional Power Benefit	69,914	69,914	69,914
PV of Farmers O&M Benefit	15,028	15,028	15,028
PV of CDM Benefit	2,411	2,411	2,411
PV of Benefit	**210,622**	**210,622**	**210,622**
Net Present Value (NPV)	**5,544**	**-13,174**	**-31,892**
Benefit-Cost Ratio (BCR)	1.03	0.94	0.87
Economic Rate of Return (ERR)	13%	9%	6%
Discount rate (%)	12%	12%	12%
Number of years	20	20	20

Economic rate of return (ERR) under Scenario 1 is 13% with BCR of 1.03 indicating that the project is slightly above breakeven, meaning that the project would deliver only a marginal benefit. Under Scenario 2 when the cost of project escalates by 20 percent, the ERR is 9% with BCR of 0.94, the project's costs outweigh the benefits and would run at a loss. Under Scenario 3, as the capital cost of project is increased by 40 percent, the ERR declines further and BCR is 0.87 indicating that the cost exceeds the benefits. Solely, on this criterion, the project should not proceed. If the life of the project is reduced to 10 or 15 years, ERR as well as BCR may turn negative (0.95 and 0.84 respectively) under Scenario 1.

While the CBA shows that the project is not economically feasible if costs rise because of implementation delays, non-availability of resources, and other factors are included. If the socio-economic costs arising out of depleted water tables, such as the food insecurity due to loss of agriculture produce, drying up of aquifers, health risks, loss of livelihood and migration of small farmers, deteriorated water quality and other risks are added, the costs would outweigh the accrued benefits by a large margin.

10.3 Risks Associated with SETs

While a benefit-cost assessment is a useful tool in evaluating economic viability of a project, it is important to consider social and political realities in the region, as well as behavioral changes to form a holistic view to help determine the viability of a project. This section lists various risk factors which, even though difficult to quantify, play an important role in assessing the overall sustainability of the SETs project in Balochistan. These risks mainly emerge from farmers' attempts to maximize short-term private gains at the cost of a large public good, which take precedence in the absence of enforcement of the legal regime, and from the tribal structure of the society. **Table 8** lists some of the major risks found around the world in projects similar to SETs which needs to be considered for decision-making.

Table 8: Risks/Concerns Associated with Solarization of Tubewells

Risks	Evidence
Over Extraction of Groundwater	• Solar pumps can work for up to 11 hrs./day during summer in Rajasthan, India. Secondly, total volume of water used for irrigation does not decrease with solar pumps as farmers expand area under irrigation. (See: Kishore et al., 2014). • Farmers have no incentive to save water as the subsidized solar pumps enable farmers to extract more groundwater in Rajasthan, India. (See: Gupta, 2017). • Solarization has intensified the race to the bottom of the aquifers in India's west-south corridor (Shah et al., 2014). • Use of STs by farmers has sucked water out of Sindh's Kaccho desert (See: http://www.ipsnews.net/2019/10/solar-tubewells-suck-water-sindh-desert/). • STs extract more groundwater than electric or diesel tubewells in Arizona (See:http://archive.azcentral.com/arizonarepublic/news/articles/20100117water-solar0117.html) • UNICEF visit to STs sites in Somalia reveal threats of overexploitation of groundwater (See:https://www.unicef.org/wash/files/UNICEF_Solar_Powered_Water_System_Assessment.pdf)
Exacerbating Socio-Economic Inequalities	• As per the project "Solarization of Electric Tubewells", STs are supposed to replace subsidized electrics tubewells in Balochistan. However, subsidized tubewells are owned by 15 % of the farmers in Balochistan (See: https://www.pide.org.pk/pdf/PolicyViewPoint/PIDE-Policy-ViewPoint-No10-2019.pdf) which has already created social and economic inequities. • In Bihar (India), subsidy on solar pumps largely benefited medium- and large-scale farmers (See: Durga et al., 2016). • In Mexico, the uptake of subsidized solar-powered irrigation systems has remained low among small farmers as they do not apply or qualify for the subsidies (See: FAO, Benefits and risks of Solar-Powered Irrigation-a global overview, 2018)
Farmers will Use Solar as well as Electric/Diesel Tubewells	• Farmers are using electric tubewells along with STs in Kharan District, Balochistan after being given free STs to extract maximum water (See: http://www.zindacademy.org/magazine/en/2019/02/28/lake-of-rains-and-increasins-number-of-tubewells-has-led-to-receding-of-underground-water-by-yar-muhammad-badini/) • Of the 31 beneficiaries of the subsidized STs in Bihar, India under the Saur Kranti Sinchai Yojana, only 4 relied exclusively on solar. Solar pumps failed to replace the traditional pumps there as they were not powerful enough and the pumps tended to act as "back up" and were routinely under-used (See: Durga et al., 2016)

Risks	Evidence
Farmers use Illegal Connections for Tubewells in Balochistan	• Farmers are operating unauthorized (electric, diesel, and solar) tubewells (approx. 21,000 in total) throughout the province or supply electricity through illegal connections. (See Khair et al., 2010) • The project ignores the presence of large number of tubewells operating through illegal connections as it plans to convert only the legal electric tubewells to solar (approx. 28,808 in total).

The major threat that the project poses is the over-exploitation of already depleting groundwater resources. In absence of monitoring and regulation enforcement of groundwater usage and QESCO's inability to curb the use of illegal tubewell connections, the risk of groundwater depletion will continue to exist regardless of which energy source is used. Unlike pumps with other energy sources, solar-run systems have low operational costs, making it cheaper to pump water in the long run and risk is substantial. Therefore, as farmers face near zero marginal costs of groundwater and the total volume of water used for irrigation may increase, i.e. farmers can expand the area under cultivation, increase cropping intensity or may simply over-irrigate[100].

11 Sustainability Matrix

Table 9 evaluates various options to make SETs sustainable and viable along with evidence and suggested mitigation measures.

Table 9: Mitigation Options for SETs

Proposed Instrument	Likely Risks	Evidence	Mitigation Measure
SETs with monitoring tools such as water metering	<u>**Water meters**</u> • Tampering • Vandalism • Meter failures • Destruction of water meters • Technical problems in meters will require regular repairing	• Failure of water meters in Jordan (*See:* https://link.springer.com/article/10.1007/s10040-003-0313-1) • Impossible to register all tubewells for successful water metering in Morocco (*See*: https://www.researchgate.net/publication/325591376_Conflicting_policies_agricultural_intensification_vs_water_conservation_in_Morocco) • Difficulty in implementing water metering in India (*See*: http://www.indiaenvironmentportal.org.in/files/file/Solar-Pump-report.pdf) • Removal of installed meters from tubewells due to farmers' resistance (*See*: Point 10.1.2 https://nepra.org.pk/tariff/Tariff/DISCOs/QESCO/2015/Determinatin%20of%20QESCO.PDF)	Registration of all Extraction Points Improved monitoring and regulatory mechanisms required
Remote Switching	• Excessive infrastructure requirements	• Requirements of Remote Switching for STs (*See*: http://www.fao.org/3/i9047en/I9047EN.pdf)	• Requires internet connectivity and communication that might not be possible all over the province

Proposed Instrument	Likely Risks	Evidence	Mitigation Measure
			• No international examples of implementation of these switches • Improved monitoring and regulatory mechanisms required to control switching of the tubewells
SETs with High efficiency irrigation system	• Does not guarantee water savings as amount of water applied remains unchanged • Increases risk of over-irrigation due to non-uniform pressure and drip discharge • Increases the risk of groundwater depletion due to increase evapotranspiration • Can potentially increase water consumption due to Rebound effect with increase in cropping area, cropping intensity and changes in cropping patterns • No guarantee of adoption as farmers have no incentives to save water • Will not work in Balochistan due to scattered landholdings	• Increased risk of over-irrigation due to drip technology in Morocco (*See*:https://www.researchgate.net/publication/325591376_Conflicting_policies_agricultural_intensification_vs_water_conservation_in_Morocco) • Increased Evapotranspiration rates in New Mexico (*See*: https://www.intera.com/expertise/water-resources/remote-sensing/remote-sensing-based-comparison-of-water-consumption/) • Increased water consumption due to increased cropping intensity and cropping area (*See*: https://www.researchgate.net/publication/320331514_Unraveling_the_enduring_paradox_of_increased_pressure_on_groundwater_through_efficient_drip_irrigation/link/59de23f0aca27247d7941725/download) • Rebound effect in Iran (See: https://www.mdpi.com/2073-445X/7/1/15 • Farmers' lack of interest in water-saving (*See*: https://www.researchgate.net/publication/266968136_Making_the_user_visible_analysing_irrigation_practices_and_farmers'_logic_to_explain_actual_drip_irrigation_performance) • Providing drip irrigation system with solar pumps does not guarantee use of these systems, an example from Rajasthan (*See*: page 61 https://www.researchgate.net/publication/281103932_Solar_irrigation_pumps_Farmers'_experience_and_state_policy_in_Rajasthan)	• Needs low-delta cropping system • Post-installation service market • Reorientation and training of Extension Workers to educate farmers about new crop watering practices • Tunnel Farming • Managing cropping intensity • Reduces losses to aquifers, that can potentially recharge groundwater • Needs to be subsidized as farmers cannot afford it • Costing of Groundwater
SETs with net-metering	• Increased risk of electricity theft and continued operations of illegal electric tubewells	• Risk of electricity theft and usage of electric tubewells as connected to the grid under Karnataka's Surya Raitha policy (*See*: https://wle.cgiar.org/content/%E2%80%98smart-solar-	• Solution for on-grid agricultural consumers. • Price paid to the farmers needs to be high to incentivize them. Low prices

Proposed Instrument	Likely Risks	Evidence	Mitigation Measure
	• Due to low electricity prices offered to farmers, they are more inclined to sell water to other farmers, as they can earn more, particularly in arid Balochistan • Lack of research on the impact of net-metering on behavioral change and water conservation	pump%E2%80%99-solution-gains-foothold-india) • Low and non-competitive prices paid to farmers in Dhundi, Gujarat (See: http://www.fao.org/3/i9047en/I9047EN.pdf) • QESCO's poor performance (*See*: Annual Financial Statements, QESCO, Various Issues)	paid do not encourage farmers to save water. • Increasing the financial burden on QESCO, after removal of subsidy and introduction of net-metering, might push the department to bankruptcy • Can be successful if it is done right and farmers are incentivized enough to conserve water

12 Policy Recommendations

Considering the international evidence and local context, the risks associated with SETs including over-extraction of groundwater, socio-economic inequities, and obsolescence of technical efficiency because of continuous depletion in the groundwater, seem to outweigh its benefits. While remedial measures such as SETs with monitoring tools (remote switching or water metering, high-efficiency irrigation system, and net-metering) can check the rampant groundwater exploitation, these policy options may not be practicable without cultural and behavioral change and awareness. Given the challenging environment for enforcement of the legal regime and monitoring mechanisms in Balochistan, STs without these instruments may provide only a temporary solution to subsidy elimination. However, it may not be sustainable in the long run as was the case in Kharan.

Comprehensive policy measures articulated below provide a clear vision, a new approach, and structural reforms that pave the way for a sustainable solution to the challenge of depleting groundwater resources, efficient water resources management, enhancing water and agriculture productivity, increasing farmers' income, and providing institutional and legal reforms and achieving social equity. Perhaps the SETs project could be viable if it is accompanied by the proposed policy measures. The suggested reforms have been aligned with the local context as any technology that does not conform to the local environment may not succeed.

Balochistan is blessed with opportunities to produce a variety of low-delta crops, therefore, attention must be given to facilitate crop diversification towards low delta and high-value crops. Diversification towards these low delta crops can provide sustainable income to small size farmers and improved crop water management and water productivity. Agricultural innovation should be encouraged to produce more per drop of water. Farmers' access to improved agricultural inputs (especially high-quality seeds) and modernization of agriculture output markets (food processing and branding) can help raising agricultural yields and create alternate livelihood opportunities in the province. Investment planning and the right strategy for rainwater harvesting, construction of a variety of dams, recharge mechanisms, development of the legal regime and its enforcement, groundwater monitoring mechanism, development of Sailaba and Khushkaba can help harnessing the full potential of 8.571 million acre feet (MAF) of unutilized flood runoff[101]in agriculture. Water literacy is also important to encourage farmers to discontinue their wasteful irrigation practices and adoption of new technologies such as tunnel farming that use less water and ensure higher yields of high-value horticulture crops.

A policy matrix is presented at **Table 10** to provide a pathway to implement comprehensive reform package. In the Matrix, ST stands for Short Term, MT for Medium Term, and LT for Long Term.

Table 10. Policy Matrix

Policy Recommendation	Proposed Process	ST/MT/ LT	Action Centre	Capacity Building Measures	Outcome
Diversification towards Low Delta, Drought resistant High-Value crops	• Investment in research to identify high-yielding varieties of low-delta crops • Pilot scale study to assess the acceptability and the potential demand of low-delta high value crops • Prepare a comprehensive plan including funding needed, branding, marketing, and collaboration between government departments • Agriculture zoning based on the climatic conditions and identify the potential of the low delta, high-value crops • Provision of high-yielding varieties of low-delta crops by engaging private sector • Improve knowledge of farmers about crop diversification to encourage adoption • Ensure profitability of low-delta crops to encourage adoption (by creating domestic and international market) • Establishment of Farm Service Centre (FSC's)	ST/MT ST ST ST ST/MT ST/MT MT MT/LT	DoAg, DG Extension, DG Research Private sector	• Capacity building of DoAg. • Reorientation and capacity building of Directorates of Agriculture Research, and Extension • Support Needed from PARC/ Academia • Support Needed from PARC/ Academia • Reorientation and training of Extension Agents • Government needs to restructure and reform Agriculture Produce Markets	• Zone specification for suitable crops and potential for low delta crops to regulate cropping pattern • Enhance farmer's knowledge about market demands • Better agriculture produce marketing • Improve farmers' income
Ensure water literacy and adoption of modern On-farm Water	• Planning for farm-level water management (Five/ten-year plan) for water conservation and crop water management	ST/MT	DoAg, DoI DG OFWM	• Capacity building/ Support to DoAg/DoI in developing this plan	• Efficient water management and enhanced water productivity

Policy Recommendation	Proposed Process	ST/MT/ LT	Action Centre	Capacity Building Measures	Outcome
Management techniques	• Assess crop-wise water demand, annual water availability, estimate shortages or surplus and prepare contingency plan to deal with the situation • Train OFWM staff in rain-harvesting and water storages techniques and water budgeting • Calculating crop water requirements and educating farmers about these requirements to reduce wasteful use of water • Provision of modern technology options such as laser leveling and moisture monitoring to improve farming and irrigation efficiency • Awareness campaigns and sessions with farmers on crop water management, irrigation scheduling water conservation practices, and usage and limitations of efficient water technologies • Awareness campaigns on improved agricultural practices such as conservation tillage, managing soil fertility, and scheduling irrigation at night to reduce loss due to evapotranspiration • Hold reflective meetings with farmers to make them realize the communal groundwater problem and engage them in developing efficient irrigation schemes, to encourage adoption • Promote the use of water efficient technologies in irrigation	ST ST ST MT ST/MT ST ST ST/MT	DoAg/ DG OFWM/ DG Ag Research DG OFWM DG OFWM DoAG DG OFWM DG Ext DG Ext DoI/DG OFWM/ DG Extension DoI/ DG OFWM	• Support from Academia, PARC, Researchers • Capacity building and Training of Extension Staff • Technology Support and training • Capacity building and training of Extension staff • Private Sector • Capacity building and training of Extension staff	• Enhanced water conservation and security • Preserving groundwater aquifer
Ensure farmers' access to quality seed and its timely availability	• Assessment of the existing capacity of private and public seed sector for production of high-quality seed varieties	ST	DoAg,	• Needs support to conduct this exercise	• Timely availability of quality seed at competitive prices

Policy Recommendation	Proposed Process	ST/MT/ LT	Action Centre	Capacity Building Measures	Outcome
	• Engage private sector in supply and distribution of the seed • Allocate needed funds • Organize farmers' days to spread awareness about quality seeds and sale points • Establish Demonstration plots to show the success of the seeds and to encourage adoption • Establish enforcement and prosecution system as provided under Seed Act	ST ST/MT ST ST/MT MT	Private Sector DG Ext DG Ext DoAg Do Ag	• Needs intervention at Govt level • Support from Govt. • Needs resources • Needs resources for establishing local laboratory and training for seed testing	• Higher yield and productivity • Improvement in farmers' income
Encourage farmers to invest in Tunnel farming	• Trainings to farmers to impart understanding of the tunnel farming method, in terms of specifications, installation, and pest/disease management • Use demonstration plots to show profitability of tunnel farming • Demonstrations and discussions with farmers who have successfully adopted tunnel farming to encourage adoption • Establishment of tunnel growers' associations • Provision of credit facility for tunnel farming, particularly to assist marginalized farmers	ST ST ST ST MT/LT	DoAg DG OFWM DG Extension DG Extension DG Ext DoAg	• Training of OFWM and Extension Staff • Needs Resources • Need support of ZTBL and Banking system	• Higher yield and productivity • Increased water productivity • Better and efficient use of inputs • Increase off-season production • Increase in farmers' income • Lower volatility in off-season prices of fruits and vegetables
Promote value addition and marketing of agricultural products	• Facilitate private sector investment in food processing plants (e.g. olive and tomato processing factories) • Incentivize private sector to invest in marketing and branding of the agricultural	MT MT	DoAg	• Needs support of Banking System • Needs incentives packages in Balochistan	• Increased value addition of agri produce • Increased private sector investment in agriculture

Policy Recommendation	Proposed Process	ST/MT/ LT	Action Centre	Capacity Building Measures	Outcome
	produce (e.g. dates, almonds, pistachios, etc.) • Ensure quality standards are being met	MT		• Needs to develop standards and grading system	• Increased employment opportunities
Water Governance and Regulation	• Review and strengthen Balochistan Ground Water Rights Administration Ordinance (BGWRA) and its enforcement by engaging relevant Stakeholders	ST	DoI DG OFWM	• Support from legal experts and international best practices	
	• Establish Balochistan Groundwater Regulatory Authority under the BGWRA, and define its' duties	ST	DoI	• Needs financial resources and expertise to establishing monitoring mechanism and its efficient use, preparation of zoning map, critical zones and its publication and developing geo-referenced database	• Efficient management of groundwater resources in the province
	• Include penalties for over-exploitation of groundwater and illegal tubewells	ST	DoI		
	• Lay proper guidelines in the BGWRA to address groundwater overdraft	ST	DOI		• Protection of groundwater aquifer and improved monitoring and regulation mechanism for effective groundwater management
	• Ensure implementation of improved Balochistan Ground Water Rights Administration Ordinance (BGWRA) for the integrated water management	ST/MT	DOI		
	• Transferring groundwater management responsibility to farmers by including them in Provincial Water Board and District-level Water Committees	ST	DOI		• Integrating locals' knowledge and perspectives in decision making to resolve the water crisis
	• Ban on installing tubewells in rain-fed or irrigated areas	ST	DOI/DOE		• Making locals' and stakeholders responsible for managing groundwater
	• Ban on deepening of tubewells	ST	DOI		
	• Development of prohibition zones, in areas where groundwater has reached alarming depths	ST	DOI		
	• Demarcation of critical groundwater zones in Balochistan	ST	DOI		
	• Controlling illegal drilling by private companies	ST	DOI/DOE / QESCO		

Policy Recommendation	Proposed Process	ST/MT/ LT	Action Centre	Capacity Building Measures	Outcome
	• Improving institutional capacity to control illegal tubewells • Establish groundwater usage and groundwater basins mechanism and regular data collection • Make data available in public domain • Publish the groundwater zoning map • Establish a geo-referenced database for existing tubewells	MT ST/MT MT MT MT	DOI/ QESCO DOI DOI DOI DOI		
Recharge of the Groundwater	• Awareness campaigns to encourage uptake of communal Karez system • Enabling environment for private sector investment in the development of these technologies • Construction of leaky dams, check dams, delay action dams and mini/small dams for recharge mechanism, particularly in high-priority areas • Rehabilitate existing dams by improving storage capacity and resolving the issue of silting • Undertake impact assessments of dams, and other recharge mechanisms • Rehabilitation of *Karez* system provided there is an engineering solution and it is feasible	ST ST MT/LT MT/LT MT LT	DoI, Private Sector	•	• Improve groundwater level and aquifer • Improve storage capacity to preserve water and reduce rain/floodwater wastage
Expansion of Water Resources	• Undertake studies to assess the potential of Khushaba and Sailaba irrigation and to identify areas for their development • Enabling environment for private sector investment in the development of these technologies	ST ST	DoI, Finance Deptt: P&D Private Sector	• Needs resources and capacity to undertake these actions	• Creation of an alternate water resource and better utilization of rainwater and floodwater • Reduced dependence on groundwater resources

Policy Recommendation	Proposed Process	ST/MT/ LT	Action Centre	Capacity Building Measures	Outcome
	• Develop *Khushkaba* farming in the rain-fed areas • Encourage *Sailaba* farming under spate irrigation with the storages/dams in the command area • Use of treated brackish water for irrigation • Rainwater harvesting through rooftops cisterns, catchment systems, ponds • Treating wastewater to be used for irrigation	ST/MT ST/MT MT MT LT			
Power sector reforms for electricity distribution	• Develop an investment plan and corporate strategy for QESCO • Promote reverse metering in domestic, public, and commercial consumers • Installation of meters for agriculture consumers • Improve operational, financial and corporate governance	ST/MT MT MT LT	QESCO MoPower	•	• Reduction in electricity distribution losses • Improve revenue recovery and decline in subsidy burden • Sustainable electricity distribution system

13 Water Pricing in Irrigation

Abiana, introduced during colonial era, is charged for the supply of canal water on the basis of the irrigated cropped area and type of crop. In Pakistan, 'Abiana' is primarily recovered based on varying charges in accordance with the crop type or area except in Punjab which has flat rate system. Kharif rate (PKR 90) is usually higher than the Rabi rate (PKR 45). However, the 'Abiana rate' is totally neutral to relative consumptive requirements of the crops, nor does it take into consideration the true cost of maintaining the system. Canal irrigation is used in only two districts of Balochistan, Naseerabad and Jaffarabad. The abiana rates in Balochistan are very low and its collection is poor. Large farmers are either exempted or concealment of cropped areas by farmers substantially reduce the assessment. On the other hand, groundwater is free of cost in Pakistan. Farmers are only required to pay the operating costs of tubewells, that are often subsidized, as in the case of Balochistan. The water charges do not reflect its true value, including its opportunity and scarcity value. Thus, the incentives to utilize water efficiently are quite weak. Therefore, it is important that the canal water may be priced closer to cost gradually and the government may also consider pricing the groundwater to disincentivize over-abstraction of water. Nevertheless, it will require strong political will accompanied by awareness campaign and implementation of measures incorporated in the Policy Matrix.

14 Way Forward

This Section focuses on specific pilot-scale interventions that aim to slow down groundwater depletion through demand and supply management and institutional development. The interventions recommended target four key areas, including:

1. Demand management through farmers' behavioral change
2. Supply management through artificial groundwater recharge
3. Improving groundwater governance, monitoring, and data collection
4. Improving QESCO's performance via reward and reprimand policy.

It is strongly recommended that all relevant stakeholders including all provincial concerned institutions, farmers, academia and researchers may be engaged at design stage, demand management and creating awareness. It is important to engage international experts to learn from international experiences to further refine policy measures suggested in this study. It is further suggested that the provincial government may design a communication strategy blend with local culture and context for awareness campaigns to address groundwater situation as well as incentives for water conservation in Balochistan. The incentives may include either cash or agricultural packages (including inputs such as high-quality seed, fertilizers, and pesticides) by diverting resources saved from subsidy. The DoI, DOE, OFWM, Agriculture Extension directorates, QESCO and a third-party donor agency can work together to implement and monitor such interventions. The private sector can also be engaged in this campaign. In Gujrat (India), the government introduced conservation credits scheme to reward farmers using less water than the pre-determined benchmark.[102] A similar project can be designed for Balochistan at a pilot-scale and lessons learnt can be used to replicate and expand the outreach of the project.

For supply management, several policies measures have been recommended in the policy matrix, including investment in recharge mechanisms and development of Sailaba and Khushkaba dryland farming systems aiming at enhancing the availability of irrigation water resources. While such investments are much needed, farmers can also be incentivized to play a role in recharging groundwater. In Pajaro valley California, farmers are offered incentives to store stormwater, which is then used to recharge groundwater.[103] A similar project, planned by OFWM and Irrigation department, can help engaging the farmers in the process of groundwater recharge in Balochistan. Improvement in the management and monitoring capacities of these departments will be needed to ensure success of such projects.

To improve groundwater governance, management and monitoring, strengthening legal regime and institutional capacity to manage and monitor is paramount. The government may design a pilot project to test community-based groundwater governance allowing the farmers to take collective responsibility and necessary actions in managing the groundwater. Lessons can be leant from Andhra Pradesh Farmers-managed Groundwater Systems[104] which allows farmers to make informed water-use decisions, providing farmers with an accurate picture of the groundwater balance through data collection for designing such project. The help of third-party organizations, water experts, farmers' water users' groups, Irrigation department and other relevant stakeholders will be essential. The district-level water committees, as formed under the BGWRA, can be reformed on the model of Texas Groundwater Conservation Districts[105], to test the success of this model in enhancing the effectiveness of these district-level water committees. Uptake of electric meters can also be encouraged by linking the meter system to financial incentives, as done in the conservation credits scheme in India.[106]

Lastly, the performance issues of QESCO, including low revenue recovery, huge distribution losses, electricity theft, and the inability to control illegal connections, can be addressed through farmers' engagement and community participation. The Social Management Strategy[107], as implemented by World Bank in Dominican Republic, can be considered for implementation in Balochistan to restore the confidence between farmers and QESCO, as well as to improve electricity distribution in the province. Farmers can be encouraged to install electricity meters and legalize their illegal connections. Moreover, through reward and penalizing for the tubewell users, QESCO can improve low revenue recovery and reduce distribution losses and electricity theft. Farmers may be incentivized through reduced outages, agriculture inputs and discounted bills based on various categories of losses at the feeder level.

There might be several unseen risks that may be associated with the recommended pilot projects; however, once the pilot project is executed, the risks and lessons learnt from the project can be employed in improving the efficacy of the interventions while scaling up.

Annexure I : Details of the CGE-W

In addition to tracking water use, the CGE-W provides detailed information on the GDP generated for each unit of water used in a commodity, as shown in Table 1. As reported in Young et. al, baseline productivity varies from US$0.13 per m3 for rice up to US$1.57 per m3 for maize. These are values that tie all value added (or GDP for a given crop) to the use of water, and so leave out the contribution of other inputs. This is an often-used approach in the irrigation literature but does not give a clear picture of the unique value of water after deducting the contribution of other inputs (Schiereling, Bill's India paper, EU (2016)).

Fortunately, we are able to use a stochastic frontier approach to get the marginal effect of adding water, when controlling for other outputs. Regression analysis in Davies (2016) found that each added acre inch of water adds 4.5% to output in kharif and 2.2% in rabi; we also know the consumptive use of water on farm from the simulations. Putting these together allows us to estimate the value of water in individual crop production, controlling for the contributions of inputs such as fertilizer, labor and land dimensions.

Productivity growth across all commodities is twice as high under RUMI compared to BAU. This highlights the clear potential for Pakistan to achieve higher incomes through moderate continued improvements in water productivity in agriculture, while reaching an upper-middle income level income would require much faster improvements in water productivity, but achievable improvements with appropriate reforms and changes to the crop mix[10].

Table 1: Economic value of water (US Cents/m^3) by crop for baseline year (2013/14) and productivity growth rates (percent) under BAU and RUMI.

	Baseline Water Productivity	Water Productivity Growth Rate (BAU)	Water Productivity Growth Rate (RUMI)
Wheat	1.23	1.5	3.4
Rice	0.89	1.3	2.7
Cotton	1.28	1.6	3.2
Sugarcane	1.27	1.2	2.6
Maize	3.16	1.7	3.3
Potato	0.62	1.1	3.4
Vegetables	1.25	1.4	2.9
Other crops	8.09	1.5	4.4
Fruit	17.43	1.9	3.7
Average	3.41	1.5	3.2

[10]To see the relative accuracy of the listed values, we used an independent calculation. The first was to use the reported costs for 6 hours of tubewell use at PKR 2000 in 2015 (AMIS, Agricultural Marketing Information Service). By assuming a pump of 15 hp that delivers about 1,000 gallons per hour, we found the cost per cubic meter was PKR 1.46, which is similar to the value found for major crops in the SAM based approach.

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